NASA TT-10002

# The Problem of Traveling in Outer Space
# The Rocket Motor

(NASA-TT-10002) THE PROBLEM OF TRAVELING IN OUTER SPACE: THE ROCKET MOTOR (NASA) 218 p

N94-14463

Unclas

G3/20 0189685

Hermann Noordung

NASA TT-10002

# The Problem of Traveling in Outer Space
# The Rocket Motor

Hermann Noordung

STI PROGRAM
SCIENTIFIC & TECHNICAL INFORMATION

NASA TECHNICAL TRANSLATION NASA - TT - 10002

# The Problem of Traveling in Outer Space
# The Rocket Motor

Hermann Noordung

Translation from German to English of "Das Problem der Befahrung des Weltraums, Der Raketen-Motor," Richard Carl Schmidt & Co.: Berlin, 1929, 188 pp.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON DC 20546 JUNE 1993

# The Problem of Traveling in Outer Space
# The Rocket Motor

Hermann Noordung

Translated by

SCITRAN COMPANY
1482 East Valley Road
Santa Barbara, California 93108
(805) 969-2413
FAX (805) 969-3439

# The Problem of Traveling in Outer Space

## The Rocket Motor

by

Hermann Noordung
Captain, Retired; BS Engineering

With 100 Figures, some in color

1929

Richard Carl Schmidt & Co.
Berlin W 62

Gimbel

Book Printing Plant
Julius Klinkhardt
Leipzig

Table of Contents

/7*

## Introduction

Since the beginning of time, mankind has witnessed an expression of his Earthly weakness and the inaccessibility of being bound to the Earth in his inadequacy of not being able to free himself of the mysterious shackles of gravity. Not without good reason then has the concept of the transcendental always been associated with the idea of weightlessness, the power "to be able freely to rise into the sky." And for most people, it still applies even today as a dogma so to speak: it is indeed unthinkable for Earthly life to be able ever to escape the Earth. Is this point of view really justified?

Keep in mind: just a few decades ago, the belief indelibly impressed upon us was widespread that it is foolhardy to hope that we would ever be able to hasten through the air like the birds. And today! In the face of this and similar superb proofs of the capability of science and technology, should mankind not dare now to tackle the last transportation problem for which a solution still eludes us: the problem of space travel? And logically: in the last few years, the "technical dream," which to date was only the stuff of fanciful novels, has become a "technical question" examined in the dispassionate works of scholars and engineers using all the support of mathematical, physical and technical knowledge and – has been deemed solvable.

[Blank Page] /8

/9

## The Power of Gravity

The most critical obstacle standing in the way of traveling in space is the attraction force of the Earth felt

* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

at all times as gravity. Then a vehicle, which is supposed to travel in outer space, must not only be able to move. It must primarily and first of all move away from the Earth; i.e., against the force of gravity, it must be able to lift itself and its payload up many thousands, even hundred of thousands of kilometers!

Because the force of gravity is an inertial force, we must first of all understand the other inertial forces existing in nature and, moreover, briefly examine what causes these forces, the two mechanical fundamental properties of mass, because the entire problem of space travel is based on these issues.

The first of these properties lies in the fact that all masses mutually attract (Law of Gravitation). The consequence of this phenomenon is that every mass exerts a so-called "force of mutual attraction" on every other mass. The attraction force, which the celestial bodies exert on other masses by virtue of their total mass, is called the force of gravity. The "Earth's force of gravity" exerted by the Earth is the reason that all objects on the Earth are "heavy", that is, they more or less have "weight" depending on whether they themselves have a larger or smaller mass. The force of mutual attraction (force of gravity) is then that much more significant, the greater the mass of the objects is between which it acts. On the other hand, its strength decreases with increasing distance (more specifically, with the square of the latter), nevertheless without its effective range having a distinct boundary /10
(Figure 1). Theoretically, the force becomes zero only at an infinite distance. Similar to the Earth, the sun, moon and, for that matter, every celestial body exerts a force of gravity corresponding to its size.

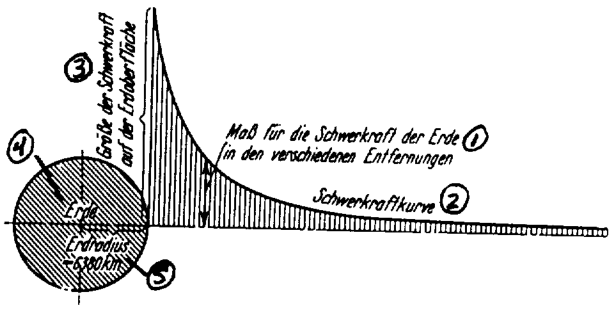


Figure 1. The curve of the Earth's force of mutual attraction (force of gravity). The strength of the attraction which decreases with the square of increasing distance is represented by the distance of the curve of the force of gravity from the horizontal axis.

Key: 1. Dimension for the Earth's force of gravity at various distances; 2. Curve of the force of gravity; 3. Magnitude of the force of gravity on the Earth's surface; 4. Earth; 5. Radius of the Earth = 6,380 km.

The second fundamental property of mass lies in the fact that all mass is always striving to continue to remain in its current state of motion (Law of Inertia). Consequently, all mass whose motion is accelerated, decelerated or has its direction changed will resist this tendency by developing counteracting, so-called "forces of inertial mass" (Figure 2).

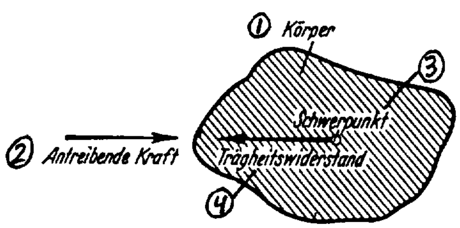


Figure 2.

Key: 1. Object; 2. Driving force; 3. Center of mass; 4. Inertia

In general, these are designated as inertia, or in a special case also as centrifugal force. The latter is the case when those forces occur due to the fact that mass is forced to move along a curved path. As is well known, the centrifugal force is always directed vertically outward from the curve of motion (Figure 3).

All of these forces: force of gravity, inertia and the centrifugal force are inertial forces. /11

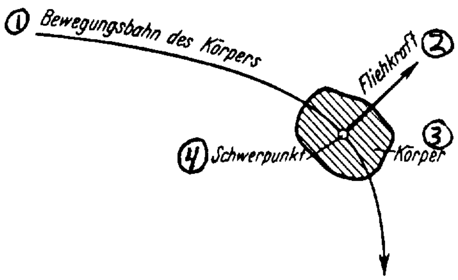


Figure 3.

Key: 1. Path of motion of the object; 2. Centrifugal force; 3. Object; 4. Center of mass

As mentioned previously, the effect of the Earth's force of gravity extends for an infinite distance, becoming weaker and weaker. We can consequently never completely escape the attractive range (the gravitational field) of the Earth, never reaching the actual gravitational boundary of the Earth. It can, nevertheless, be calculated what amount of work would theoretically be required in order to overcome the Earth's total gravitational field. To this end, an energy not less than 6,380 meter-tons would have to be used for every kilogram of load. Furthermore, it can be determined at what velocity an object would have to be accelerated away from the Earth, so that it no longer returns to Earth. The velocity is 11,180 meters per second. This is the same velocity at which an object would strike the Earth's surface if it fell freely from an infinite distance onto the Earth. In order to impart this velocity to a kilogram of mass, the same amount of work of 6,380 meter-tons is required which, as noted previously, would have to be expended to overcome the total Earth's gravitational field per kilogram of load.

If the Earth's attraction range could never actually be escaped from, possibilities would nevertheless exist for an object to escape from the gravitational effect of the Earth, and more specifically, by the fact that it is also subjected to the effect of other inertial forces counterbalancing the Earth's force of gravity. According to our previous consideration about the fundamental properties of mass, only the following forces are possible: either the forces of mutual attraction of neighboring stars or forces of inertial mass self-activated in the object in question.

/12

## The Practical Gravitational Boundary of the Earth

First of all, we want to examine the previously cited possibility. Because like the Earth every other celestial body also has a gravitational field which extends out indefinitely, losing more and more strength the further out it goes, we are – theoretically, at least – always under the simultaneous gravitational effect of all stars. Of this effect, only the gravitational effect of the Earth and, to some degree, that of our moon is noticeable to us, however. In the area of the Earth's surface, in which mankind lives, the force of the Earth's attraction is so predominately overwhelming that the gravitational effect exerted by other celestial bodies on that area for all practical purposes disappears compared to the Earth's attraction.

Something else happens, however, as soon as we distance ourselves from the Earth. That attraction force continually decreases in its effect, while, on the other hand, the

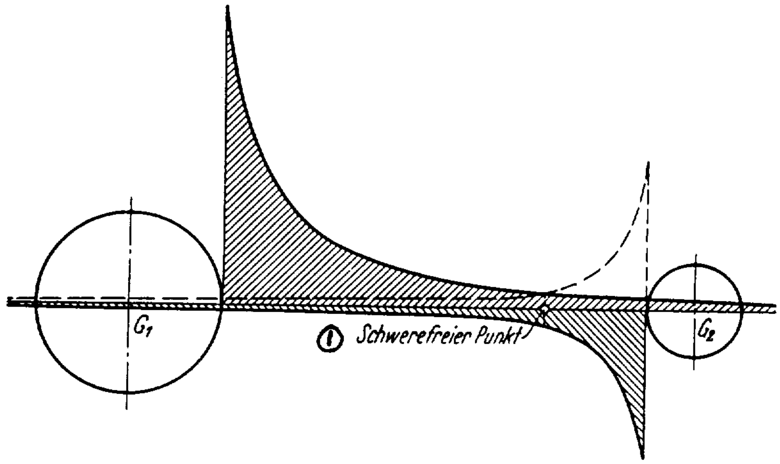


Figure 4. The curve of the gravitational fields of two neighboring stars $G_1$ and $G_2$ is represented as in Figure 1, with the exception that the gravitational curve of the smaller celestial body $G_2$ was drawn below the line connecting the centers because its attraction force counteracts that of the larger star $G_1$. The point free of gravitational effects is located where both gravitational fields are opposite and equal to one another and, therefore, offset their effect.

Key: 1. Point free of gravitational effects

effect of the neighboring stars increases continually. /13
Since the effect counterbalances the Earth's force of gravity, a point must, after all, exist seen from the Earth in every direction at which these attraction forces maintain equilibrium according to their strengths. On this side of that location, the gravitational effect of the Earth starts to dominate, while on the other side, that of the neighboring star. This can be designated as a practical boundary of the gravitational field of the Earth, a concept which, however, may not be interpreted in the strict sense, taking into consideration the large difference and continual changing of the position of the neighboring stars in relation to the Earth.

At individual points on the practical gravitational boundary (in general, on those which are on the straight line connecting the Earth and a neighboring star), the attraction forces also are offset according to the direction, such that at those points a completely weightless state exists. A point of this nature of outer space is designated as a so-called "point free of gravitational effects" (Figure 4).

However, we would find ourselves at that point in an only insecure, purely labile state of weightlessness, because at the slightest movement towards one side or the other, we are threatened with a plunge either onto the Earth or onto the neighboring star.

## Free Orbit

In order to attain a secure, stable state of weightlessness, we would have to escape the effect of gravity in the second way: with the aid of inertial forces.

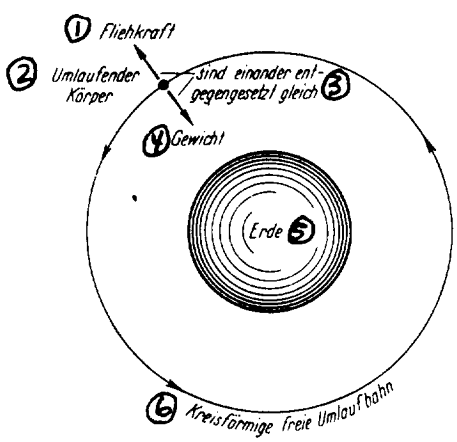


Figure 5. Circular free orbiting of an object around the Earth. The object's weight is offset by the centrifugal force generated during the orbiting. The object is, therefore, in a stable state of free suspension in relation to the Earth.

Key: 1. Centrifugal force; 2. Orbiting object; 3. Are opposite and equal to one another; 4. Weight; 5. Earth; 6. Circular free orbit

This is attained when the attracting celestial body, for example, the Earth, is orbiting in a free orbit at a corresponding velocity (gravitational motion). The centrifugal force occurring during the orbit and always directed outward maintains equilibrium with the attraction force (more specifically, it is the only force when the motion is circular (Figure 5)), or simultaneously with other inertial forces occurring when the orbit has another form (ellipse, hyperbola, parabola, Figure 6). /14

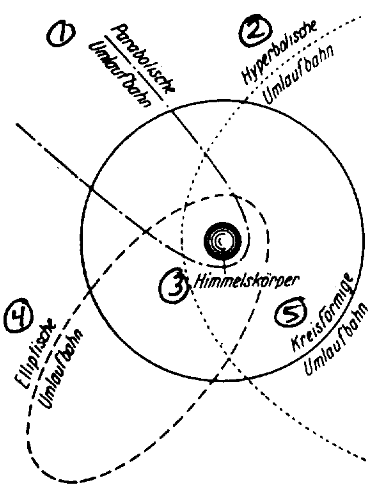


Figure 6. Various free orbits around a celestial body. In accordance with the laws of gravitational movement, a focal point of the orbit (the center in the case of a circle) must always coincide with the center of mass (gravitational point) of the orbiting celestial body.

Key: 1. Parabolic orbit; 2. Hyperbolic orbit; 3. Celestial body; 4. Elliptical orbit; 5. Circular orbit

All moon and planet movements occur in a similar fashion. Because, by way of example, our moon continuously orbits the Earth at an average velocity of approximately 1,000 meters per second, it does not fall onto the Earth even though it is in the Earth's attraction range, but instead is suspended freely above it. And likewise the Earth does not plunge into the sun's molten sea for the simple reason that it continuously orbits the sun at an average velocity of approximately 30,000 meters per second. As a result of the centrifugal force generated during the orbit, the effect of the sun's gravity on the Earth is offset and, therefore, we perceive nothing of its existence. Compared to the sun, we are "weightless" in a "stable state of suspension;" from a practical point of view, we have been "removed from its gravitational effect."

The shorter the distance from the attracting celestial /15 body in which this orbiting occurs, the stronger the effect of the attraction force at that point. Therefore, the greater the counteracting centrifugal force and consequently the orbiting velocity must be (because the centrifugal force increases with the square of the orbiting velocity). While, by way of example, an orbiting velocity of only approximately 1,000 meters per second suffices at a distance of the moon from the Earth, this velocity would have to attain the value of approximately 8,000 meters per second for an object which is supposed to orbit near the Earth's surface in a suspended state (Figure 7).

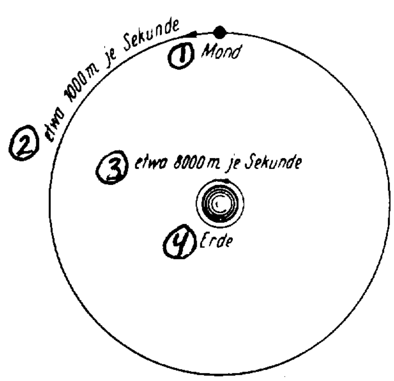


Figure 7. The orbiting velocity is that much greater the closer the free orbit movement occurs to the center of attraction.

Key: 1. Moon; 2. Approximately 1,000 meters per second; 3. Approximately 8,000 meters per second; 4. Earth

In order to impart this velocity to an object, that is, to bring it into a stable state of suspension in relation to the Earth in such a manner, and as a result to free it from the Earth's gravity, an amount of work of about 3,200 meter-tons per kilogram of weight is required.

## Maneuvering in the Gravitational Fields of Outer Space

Two basic possibilities exist in order to escape the gravitational effect of the Earth or of another star: reaching the practical gravitational boundary or transitioning into a free orbit. As to which possibility will be employed depends on the respective intended goals.

Thus, for example, in the case of long-distance travel through outer space, it would generally depend on maneuvering in such a fashion that those celestial bodies, in whose attraction range (gravitational field) the trip takes place, will be circled in a free orbit suspended in /16 space (that is, only in suspension without power by a man-made force) if there is no intention to land on them. A longer trip would consist, however, of parts of orbits of this nature (suspension distances), with the transition from the gravitational field of one star into that of a neighboring one being caused generally by power from a man-made force.

If we wanted to remain at any desired altitude above a celestial body (e.g., the Earth) for a longer period, then we will continuously orbit that body at an appropriate velocity in a free circular orbit, if possible, and, therefore, remain over it in a stable state of suspension.

When ascending from the Earth or from another star, we must finally strive either to attain the practical gravitational boundary and, as a result, the "total separation" (when foregoing a stable state of suspension) or transitioning into a free orbit and as a result into the "stable state of suspension" (when foregoing a total separation). Or, finally, we do not intend for the vehicle continually to escape the gravitational effect when ascending at all, but are satisfied to raise it to a certain altitude and to allow it to return immediately to Earth again after reaching this altitude (standard trajectory).

In reality, these differing cases will naturally not always be rigorously separated from one another, but frequently supplement one another. The ascent, however, will always have to take place by power from a man-made force and require a significant expenditure of energy, which – in the case of an ascending object, it must also escape from the gravitational effect – for the Earth is the enormous value of around 3,200 up to 6,400 meter-tons per kilogram of the load to be raised. Or – which amounts to the same thing – requires imparting the huge, cosmic velocity of approximately 8,000 to 11,200 meters per second, that is about 12 times the velocity of an artillery projectile!

/17

## The Armor Barrier of the Earth's Atmosphere

Besides the force of gravity, the atmosphere, which many celestial bodies have – quite naturally that of the Earth, in particular – also plays an extremely important role for space travel. While the atmosphere is very valuable for the landing, it, on the other hand, forms a particularly significant obstacle for the ascent.

According to observations of falling meteors and the northern lights phenomena, the height of the entire atmosphere of the Earth is estimated at several (perhaps 400) kilometers (Figure 8).

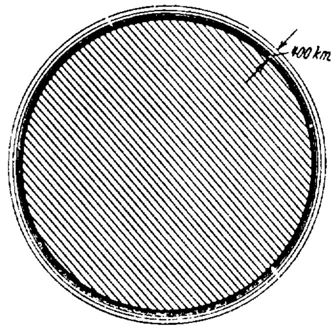


Figure 8. Assuming that the atmosphere is approximately 400 km high, the diagram shows its correct relationship to the Earth.

Nevertheless, only in its deepest layers several kilometers above the Earth, only on the "bottom of the sea of air" so to speak, does that air density exist which is necessary for the existence of life on Earth. Then the air density decreases very quickly with increasing altitude and is, by way of example, one-half at an altitude of 5 km and only one-sixth at an altitude of 15 km, both altitudes being measured from sea level (Figure 9).

This condition is of critical importance for the question of space travel and is beneficial to it. Then, as is well known, air resists every moving object. During an increasing velocity of motion, the resistance increases, however, very rapidly, and more specifically, in a quadratic relationship. Within the dense air layers near the Earth, it reaches such high values at the extreme velocities considered for space travel that as a result the amount of work necessary for overcoming the gravitational field during ascent, as mentioned previously, is increased considerably and must also be taken into consideration to a substantial /18 degree when building the vehicle. However, since the density of the air fortunately decreases rapidly with increasing altitude, its resistance also becomes smaller very quickly and can as a result be maintained within acceptable limits. Nevertheless, the atmosphere is a powerful obstacle during ascent for space travel. It virtually forms an armored shield surrounding the Earth on all sides. Later, we will get to know its importance for returning to Earth.

## The Highest Altitudes Reached to Date

There has been no lack of attempts to penetrate into the highest altitudes. Up to the present, mankind has been able to reach an altitude of 11,800 meters in an airplane, 12,000 meters in a free balloon, and 8,600 meters on Mount Everest (Figure 9).

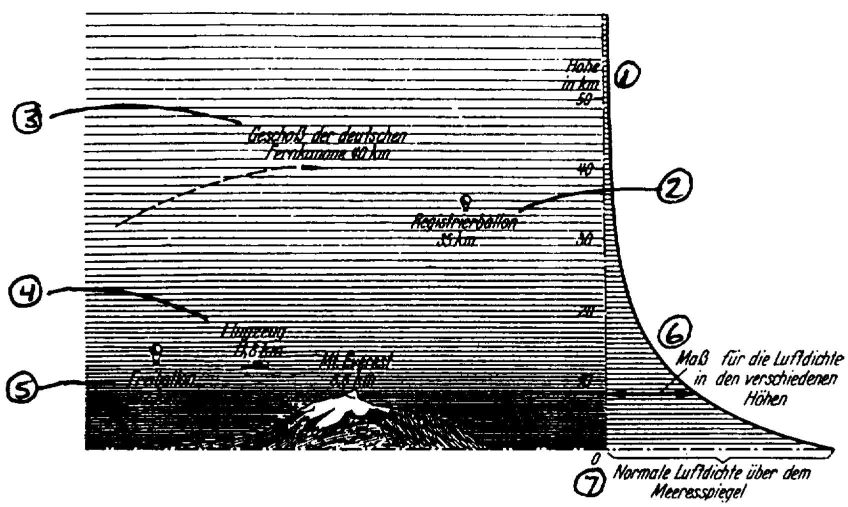


Figure 9. With increasing altitude, the density of air decreases extremely rapidly, as can be seen from the curve drawn on the right and from the intensity of the shading.

Key: 1. Altitude in km; 2. Balloon sonde 35 km; 3. Projectile of the German long-range cannon; 4. Airplane 8 km; 5. Free balloon 12 km; 6. Scale for the density of air at various altitudes; 7. Normal density of air above sea level

So-called balloon sondes have attained even higher altitudes. They are unmanned rubber balloons which are supposed to carry very lightweight recording devices as high as possible.

Since the air pressure decreases continually with /19 increasing altitude, the balloon expands more and more during the ascent until it finally bursts. The recording devices attached to a parachute gradually fall, recording automatically pressure, temperature and the dampness of the air. Balloon sondes of this type were able to reach an altitude up to approximately 35 kilometers. Moreover, the projectiles of the famous German long-range cannon, which fired on Paris, reached an altitude of approximately 40 kilometers. Nevertheless, what is all of this in comparison to the tremendous altitudes which we would have to ascend in order to reach into empty outer space or even to alien celestial bodies!

## The Cannon Shot into Outer Space

It appears obvious when searching for the means to escape the shackles of the Earth to think of firing from a correspondingly powerful giant cannon. This method would have to impart to the projectile enormous energy which it requires for overcoming gravity and for penetrating the atmosphere entirely as a kinetic force, that is, in the form of velocity. This requires, however, that the projectile must have already attained a velocity of not less than around 12,000 meters per second when leaving the ground if, besides the lifting energy, that energy for overcoming air drag is also taken into account.

Even if the means of present day technology would allow a giant cannon of this type to be built and to dare firing its projectile into space (as Professor H. Lorenz in Danzig

has verified, we in reality do not currently have a propellant which would be sufficiently powerful for this purpose) — the result of this effort would not compensate for the enormous amounts of money required to this end. In the best case, such an "ultra artillerist" would be able to boast about being the first one to accelerate an object from the Earth successfully or perhaps to have also fired at the moon. Hardly anything more is gained by this because /20
everything, payload, recording devices, or even passengers taken in this "projectile vehicle" during the trip, would have to be transformed into mush in the first second, because no doubt only massive steel would be able to withstand the enormous inertial pressure acting upon all parts of the projectile during the time of the firing, during which the projectile must be accelerated out of a state of rest to a velocity of 12,000 meters per second within a period of only a few seconds (Figure 10), completely ignoring the great heat occurring as a result of friction in the barrel of the cannon and especially in the atmosphere to be penetrated.

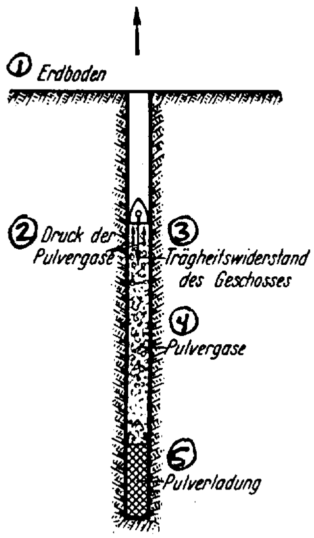


Figure 10. The Jules Verne giant cannon for firing at the moon. The projectile is hollow and is designed for transporting human beings. The tube is embedded as a shaft in the ground.

Key: 1. Ground; 2. Pressure of the powder gases; 3. Inertia of the projectile; 4. Powder gases; 5. Powder charge

## The Reaction

This method is, for all practical purposes, not useable. That energy, which the space vehicle requires for overcoming gravity and air drag, as well as for moving in empty space, must be supplied to it in another manner, that is, by way of example, bound in the propellants carried on board the vehicle during the trip. Furthermore, a propulsion motor must also be available which allows the propulsion force during the flight to change or even shut off, to alter the direction of flight, and to work its way up gradually to those high, almost cosmic velocities necessary for space flight without endangering passengers or the payload.

/21

But how do we achieve all of this? How is movement supposed to be possible in the first place since in empty space neither air nor other objects are available on which the vehicle can support itself (would be able to push off from, in a manner of speaking) in order to continue its movement in accordance with one of the methods used to date? (Movement by foot for animals and human beings, flapping of wings by birds, driving wheels for rolling trucks, screws of ships, propellers, etc.)

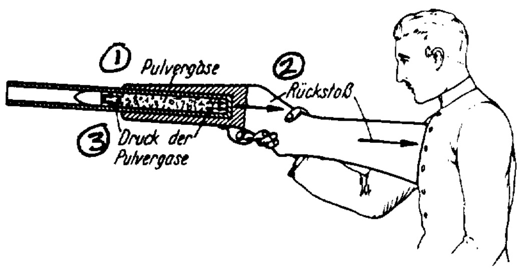


Figure 11. The "reaction" when firing a rifle

Key: 1. Powder gases; 2. Recoil; 3. Pressure of the powder gases.

A generally known physical phenomenon offers the means for this. Whoever has fired a powerful rifle (and in the present generation, these people ought not to be in short supply) has, no doubt, clearly felt the so-called "reaction" (maybe the experience was not altogether a pleasant one). This is a powerful action which the rifle transfers to the shooter against the direction of discharge when firing. As a result, the powder gases also press back onto the rifle with the same force at which they drive the projectile forward and, therefore, attempt to move the rifle backwards (Figure 11).

However, even in daily life, the reaction phenomenon /22 can be observed again and again, although generally not in such a total sense: thus, for example, when a movable object is pushed away with the hand (Figure 12), exactly the same thrust then imparted to the object is, as is well known,

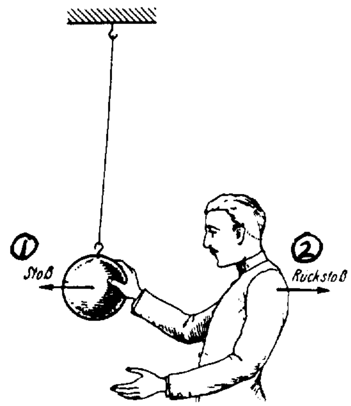


Figure 12. Even when a person quickly shoves an easily movable, bulkier object (e.g., a freely suspended iron ball) away from himself, he receives a noticeable "reaction" automatically.

1. Action; 2. Reaction.

also received by us at the same time in an opposite direction as a matter of course. Stated more precisely: this "reaction" is that much stronger, and we will as a result also fall back of our own accord that much further, the stronger we pushed. However, the "velocity of repulsion," which the affected object being pushed away attains as a result, is also that much greater. On the other hand, we will be able to impart a velocity that much greater to the object being pushed away with one and the same force, the less weight the object has (i.e., the smaller the mass). And likewise we will also fall back of our own accord that much further, the lighter we are (and the less we will fall back, the heavier we are).

The physical law, which captures this phenomenon, is called the "law maintaining the center of gravity." It states that the common center of gravity of a system of objects always remains at rest if they are set in motion only by internal forces, i.e., only by forces acting among these objects.

In our first example, the pressure of powder gases is the internal force acting between the two objects: projectile and rifle. While under its influence the very small projectile receives a velocity of many hundreds of meters per second, the velocity, on the other hand, which the much heavier rifle attains in an opposite direction is so small that the resulting recoil can be absorbed by the

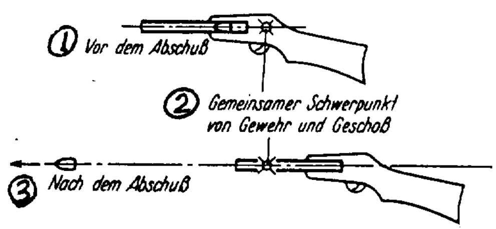


Figure 13. If the "reaction" of the rifle is not absorbed, it continually moves backwards (after firing), and more specifically, in such a manner that the common center of gravity of rifle and projectile remains at rest.

Key: 1. Prior to firing; 2. Common center of gravity of the rifle and projectile; 3. After firing

/23

shooter with his shoulder. If the person firing the rifle did not absorb the recoil and permitted the rifle to move backwards unrestrictedly (Figure 13), then the common center of gravity of the projectile and rifle would actually remain at rest (at the point where it was before firing), and the rifle would now be moving backwards.

## The Reaction Vehicle

If the rifle was now attached to a light-weight cart (Figure 14) and fired, it would be set in motion by the force of the recoil. If the rifle was fired continually and rapidly, approximately similar to a machine gun, then the cart would be accelerated, and could also climb, etc. This would be a vehicle with reaction propulsion, not the most complete, however. The continual movement of a vehicle of this type takes place as a result of the fact that it continually accelerates parts of its own mass (the projectiles in the previous example) ahead of it opposite to the direction of motion and is repelled by these accelerated parts of mass.

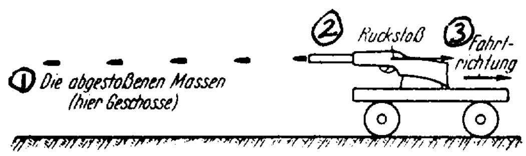


Figure 14. A primitive vehicle with reaction propulsion: The cart is continually moved by unremitting firing of a rifle by virtue of the "reaction" generated as a result.

Key: 1. The masses flung away (the projectiles in this case); 2. Recoil; 3. Direction of travel

It is clear as a result that this type of propulsion will then be useful when the vehicle is in empty space and its environment has neither air nor something else available on which a repulsion would be possible. Indeed, the propulsion will only then be able to develop its greatest efficiency because all external resistances disappear.

For the engineering design of a vehicle of this type, we must now strive to ensure that for generating a specific propulsion, on the one hand, as little mass as possible must /24 be repelled and, on the other hand, that its repulsion proceeds in a simple and operationally safe way, if at all possible.

To satisfy the first requirement, it is basically necessary that the velocity of repulsion be as large as possible. In accordance with what has already been stated, this can be easily understood even without mathematical substantiation, solely through intuition: then the greater the velocity I want to push an object away from me, the greater the force I have to press against it. Again, in accordance with what has already been stated, the greater the opposite force will be which reacts on me as a result; this is the reaction produced by the repulsion of precisely this mass.

Furthermore, it is not necessary that larger parts of mass are repelled over longer time intervals, but rather that masses as small as possible are repelled in an uninterrupted sequence. Why this also contributes to keeping the masses to be repelled as low as possible, follows from mathematical studies which will not be used here, however. As can be easily understood, however, the fact is that the latter must be required in the interest of operational safety, because the forward thrust would otherwise occur in a reverse direction, something which would be damaging to the vehicle and its contents. Only one acting propulsion force as constant as possible is useful from a practical standpoint.

## The Rocket

These conditions can best be conformed to when the repulsion of the masses is caused by the fact that suitable substances carried on the vehicle are initially burned and the resulting gases of combustion are then permitted to escape towards the rear – "to exhaust." In this manner, the masses attain repulsion in the smallest particles (molecules of the combustion gases) and the energy being freed during the combustion and being converted into a gas pressure provides the necessary "internal force" for this.

The well known fireworks rocket represents a vehicle /25
of this type in a simple implementation (Figure 15). Its purpose is to lift a so-called "bursting charge": there are all sorts of fireworks which explode after reaching a certain altitude either to please the eye in a spectacular shower of sparks or (in warfare, by way of example) to provide for lighting and signaling.

The continual movement (lifting) of a fireworks rocket of this type takes place as a result of a powder charge carried in the rocket, designated as the "propellant." It is ignited when the rocket takes off and then gradually burns out during the climb, with the resulting combustion gases escaping towards the rear (downward) and as a result — by virtue of its reaction effect — producing a continuous propulsion force directed forward (up) in the same way as was previously discussed.

Now, a rocket which is supposed to serve as a vehicle for outer space would, however, have to look considerably different than a simple fireworks rocket.

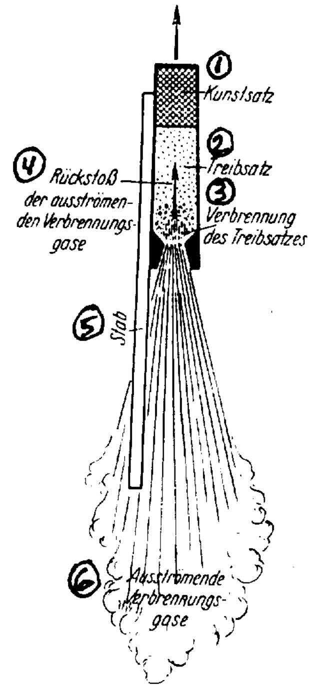


Figure 15. Fireworks rocket in a longitudinal section. The attached guide stick serves to inhibit tumbling of the rocket.

Key: 1. Bursting charge; 2. Propellant; 3. Combustion of the propellant; 4. Reaction of the escaping combustion gases; 5. Guide stick; 6. Escaping combustion gases

## Previous Researchers Addressing the Problem of Space Flight

The idea that the reaction principle is suitable for the propulsion of space vehicles is not new. Around 1660, the Frenchman Cyrano de Bergerac in his novels described, in /26 a very fantastic way, however, space travels in vehicles lifted by rockets. Not much later, the famous English scholar Isaac Newton pointed out in a scientific form the possibilities of being able to move continually even in a vacuum using the reaction process. In 1841, the Englishman Charles Golightly registered a patent for a rocket flight machine. Around 1890, the German Hermann Ganswindt and a few years later the Russian Tsiolkovsky made similar suggestions public for the first time. Similarly, the famous French author Jules Verne discussed in one of his writings the application of rockets for purposes of continual movement, although only in passing. The idea of a space ship powered by the effects of rockets emerged, however, very definitely in a novel by the German physicist Kurt Laßwitz.

Yet only in the most recent times, serious scientific advances have been undertaken in this discipline, and indeed apparently from many sides at the same time: a relevant work by Professor Dr. Robert H. Goddard appeared in 1919. The work of Professor Hermann Oberth, a Siebenbüger saxon, followed in 1923. A popular representation by Max Valier, an author from Munich, was produced in 1924 and a study by Dr. Walter Hohmann, an engineer from Essen, in 1925. Publications by Dr. Franz Edler von Hoefft, a chemist from Vienna, followed in 1926. New relevant writings by Tsiolkovsky, a Russian professor, were published in 1925 and 1927.

Also, several novels, which treated the space flight problem by building on the results of the most recent scientific research specified above, have appeared in the last few years, in particular, those from Otto Willi Gail standing out.

Before we turn our attention now to the discussion of the various recommendations known to date, something first must be said regarding the fundamentals of the technology of motion and of the structure of rocket space vehicles.

/27

## The Travel Velocity and the Efficiency for Rocket Vehicles

It is very important and characteristic of the reaction vehicle that the travel velocity may not be selected arbitrarily, but is already specified in general due to the special type of its propulsion. Since continual motion of a vehicle of this nature occurs as a result of the fact that it repels parts of its own mass, this phenomenon must be regulated in such a manner that all masses have, if possible, released their total energy to the vehicle following a successful repulsion, because the portion of energy the masses retain is irrevocably lost. As is well known, energy of this type forms, among others, the kinetic force inherent in every object in motion. If now no more energy is supposed to be available in the repelling mass, then they must be at rest vis-a-vis the environment (better stated: vis-a-vis its state of motion before starting) following a successful repulsion. In order, however, to achieve this, the travel velocity must be of the same rate as the velocity of repulsion, because the velocity, which the masses have before their repulsion (that is, still as parts of the vehicle), is just offset by that velocity which was imparted to them in an opposite direction during the repulsion (Figure 16). As a result of the repulsion, the masses subsequently arrive in a relative state of rest and drop vertically to the ground as free falling objects.

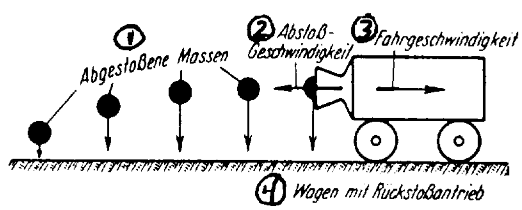


Figure 16. The travel velocity is equal to the velocity of repulsion. Consequently, the velocity of the repelling masses equals zero after the repulsion, a point that can be seen from the figure by the fact that they drop vertically.

Key: 1. Repelling masses; 2. Velocity of repulsion; 3. Travel velocity; 4. Cart with reactive propulsion

Under this assumption in the reaction process, no energy is lost; reaction itself works with a (mechanical) /28 efficiency of 100 percent (Figure 16). If the travel velocity was, on the other hand, smaller or larger than the velocity of repulsion, then this "efficiency of reaction" would also be correspondingly low (Figure 17). It is completely zero as soon as the vehicle comes to rest during a functioning propulsion.

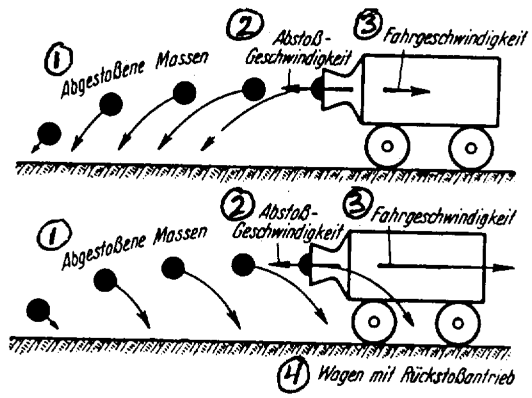


Figure 17. The travel velocity is smaller (top diagram) or larger (lower diagram) than the velocity of repulsion. The repelling masses still have, therefore, a portion of their velocity of repulsion (top diagram) or their travel velocity (lower diagram) following a resultant repulsion, with the masses sloping as they fall to the ground, as can be seen in the figure.

Key: 1. Repelling masses; 2. Velocity of repulsion; 3. Travel velocity; 4. Cart with reactive propulsion

This can be mathematically verified in a simple manner, something we want to do here by taking into consideration the critical importance of the question of efficiency for the rocket vehicle. If the general expression for efficiency is employed in the present case: "Ratio of the energy gained to the energy expended"[2], then the following formula is arrived at

$$\eta_r = \left(2 - \frac{v}{c}\right)\frac{v}{c}$$

/29

as an expression for the efficiency of the reaction $\eta_r$ as a function of the existing ratio between travel velocity v and the velocity of repulsion c.

---

2 $\eta_r$ = Energy gained/Energy expended

= (Energy expended - Energy lost)/ Energy expended

Energy expended = $\frac{m c^2}{2}$,

Energy lost = $\frac{m (c - v)^2}{2}$,

with m being the observed repulsion masses and (c -v) being their speed of motion still remaining after the repulsion (according to what has already be stated, this means a kinetic force lost to the vehicle).
It follows from that:

$$\eta_r = \frac{\frac{m c^2}{2} - \frac{m (c - v)^2}{2}}{\frac{m c^2}{2}} = \left(2 - \frac{v}{c}\right)\frac{v}{c}.$$

Table 1

| Ratio of the travel velocity v to the velocity of repulsion c<br>v/c | Efficiency of the Reaction $\eta_r$<br>$\eta_r = \left(2 - \frac{v}{c}\right)\frac{v}{c}$ | $\eta_r$ in percentages (rounded-up) |
|---|---|---|
| 0 | 0 | 0 |
| 0.01 | 0.0199 | 2 |
| 0.05 | 0.0975 | 10 |
| 0.1 | 0.19 | 19 |
| 0.2 | 0.36 | 36 |
| 0.5 | 0.75 | 75 |
| 0.8 | 0.96 | 96 |
| 1 | 1 | 100 |
| 1.2 | 0.96 | 96 |
| 1.5 | 0.75 | 75 |
| 1.8 | 0.36 | 36 |
| 2 | 0 | 0 |
| 2.5 | -1.25 | -125 |
| 3 | -3 | -300 |
| 4 | -8 | -800 |
| 5 | -15 | -1500 |

/30

In Table 1, the efficiency of the reaction $\eta_r$ is computed for various values of this v/c ratio using the above formula. If, for example, the v/c ratio was equal to 0.1 (i.e., v = 0.1 c, thus the travel velocity is only one-tenth as large as the velocity of repulsion), then the efficiency of the reaction would only be 19 percent. For v/c = 0.5 (when the travel velocity is one-half as large as the velocity of repulsion), the efficiency would be 75 percent, and for v/c = 1 (the travel velocity equals the velocity of repulsion) – in agreement with our previous consideration –, the efficiency would even be 100 percent. If the v/c ratio becomes greater than 1 (the travel velocity exceeds the velocity of repulsion), the efficiency of the reaction is diminished again and, finally, for v/c = 2 it again goes through zero and even becomes negative (at travel velocities more than twice as large as the velocity of repulsion).

The latter appears paradoxical at first glance because the vehicle gains a travel velocity as a result of repulsion and apparently gains a kinetic force as a result! Since the loss of energy, resulting through the separation of the repulsion mass loaded very heavily with a kinetic force due to the large travel velocity, now exceeds the energy gain realized by the repulsion, an energy loss nevertheless results for the vehicle from the entire process — despite the velocity increase of the vehicle caused as a result. The energy loss is expressed mathematically by the negative sign of the efficiency. Nonetheless, these efficiencies resulting for large values of the v/c ratio have, in reality, only a more or less theoretical value.

It can, however, clearly and distinctly be seen from /31 the table how advantageous and, therefore, important it is that the rate of the travel velocity approaches as much as possible that of the velocity of repulsion in order to achieve a good efficiency of reaction, with certain differences (even up to $v = 0.5\ c$ and/or $v = 1.5\ c$) being, nevertheless, not too important because fluctuations of the efficiency near its maximum are fairly slight. Accordingly, it can be stated that the optimum travel velocity of a rocket vehicle is approximately between one-half and one and one-half times the value of its velocity of repulsion.

When, as is the case here, the reaction vehicle is a rocket vehicle and consequently the repulsion of masses takes place through appropriate combustion and exhausting of fuels carried on the vehicle, then, in the sense of the requirement just identified, the travel velocity must be as much as possible of the same magnitude as the exhaust velocity (Figure 18). To a certain extent, this again requires, however, that the travel velocity conforms to the type of fuel used in each case, because another highly achievable exhaust velocity is characteristic of the fuel.

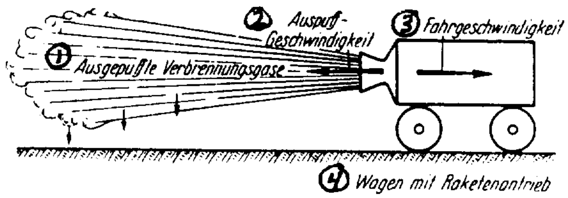


Figure 18. For a rocket vehicle, the travel velocity must as much as possible be equal to the exhaust velocity.

Key: 1. Exhausted gases of combustion; 2. Exhaust velocity; 3. Travel velocity; 4. Cart with rocket propulsion

This fundamental requirement of rocket technology is above all now critical for the application of rocket vehicles. According to what has already been stated, the velocity of repulsion should then be as large as possible. Actually, the possible exhaust velocities are thousands of /32 meters per second and, therefore, the travel velocity must likewise attain a correspondingly enormous high value which is not possible for all vehicles known to date, if the efficiency is supposed to have a level still useable in a practical application.

This can be clearly seen from Table 2, in which the efficiencies corresponding to the travel velocities at various velocities of repulsion are determined for single important travel velocities (listed in Column 1).

It can be seen from Column 2 of the table, which lists the efficiency of reaction, how small the optimization of the rocket propulsion is at velocities (of at most several hundred kilometers per hour) attainable by our present vehicles.

This stands out much more drastically if, as expressed in Column 3, the total efficiency is considered. This is arrived at by the fact that the losses are taken into account which are related to the generation of the velocity of repulsion (as a result of combustion and exhausting of the fuel). These losses have the effect that only an exhaust velocity smaller than that velocity which would be theoretically attainable in the best case for the affected fuel can always be realized in practice. As will be subsequently discussed in detail[3], the related utilization of the fuel could probably be brought up to approximately 60 percent. For benzene by way of example, an exhaust velocity of 3,500 meters per second at 62 percent and one of 2,000 meters per second at 20 percent would result. Column 3 of Table 2 shows the total efficiency for both cases (the efficiency is now only 62 percent and/or 20 percent of the corresponding values in Column 2, in the sense of the statements made).

---

[3] See Page 59 for a discussion of the "internal efficiency" of the rocket motor.

Table 2

| 1 | | 2 | | | | | | | 3 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Travel velocity v in** | | **Efficiency of the Reaction** $\eta_r = \left(2 - \frac{v}{c}\right)\frac{v}{c}$ | | | | | | | **Total Efficiency of the vehicle propulsion** $\eta = \eta_r \eta_i$ **for benzene and liquid oxygen as a fuel** | |
| | | Expressed in percentages for the following velocities of repulsion **c** in m/sec: | | | | | | | | |
| km/h | m/s | 1000 | 2000 | 2500 | 3000 | 3500 | 4000 | 5000 | 2000 | 3500 |
| 40 | 11 | 2.2 | 1.2 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.4 |
| 100 | 28 | 4.6 | 2.8 | 2.2 | 1.8 | 1.6 | 1.4 | 1.2 | 0.6 | 1 |
| 200 | 56 | 11 | 5.5 | 4.5 | 3.8 | 3.2 | 2.8 | 2.2 | 1.1 | 2 |
| 300 | 83 | 16 | 8 | 6.5 | 5.5 | 4.7 | 4 | 3.4 | 1.6 | 3 |
| 500 | 140 | 26 | 13 | 11 | 9 | 8 | 7 | 5.5 | 2.7 | 5 |
| 700 | 200 | 36 | 19 | 15 | 13 | 11 | 10 | 8 | 4 | 7 |
| 1000 | 300 | 51 | 28 | 23 | 19 | 16 | 14 | 12 | 6 | 10 |
| 1800 | 500 | 75 | 44 | 36 | 31 | 27 | 23 | 19 | 9 | 17 |
| 3000 | 1000 | 100 | 75 | 64 | 56 | 50 | 44 | 36 | 15 | 31 |
| 5400 | 1500 | 75 | 94 | 84 | 75 | 67 | 60 | 51 | 19 | 42 |
| 7200 | 2000 | 0 | 100 | 96 | 89 | 81 | 75 | 64 | 20 | 50 |
| 9000 | 2500 | -125 | 94 | 100 | 97 | 92 | 86 | 75 | 19 | 57 |
| 10800 | 3000 | -300 | 75 | 96 | 100 | 98 | 94 | 84 | 15 | 61 |
| 12600 | 3500 | -525 | 44 | 84 | 97 | 100 | 99 | 91 | 9 | 62 |
| 14400 | 4000 | -800 | 0 | 64 | 89 | 98 | 100 | 96 | 0 | 61 |
| 18000 | 5000 | -1500 | -125 | 0 | 56 | 81 | 94 | 100 | -25 | 50 |
| 21600 | 6000 | | -300 | -96 | 0 | 50 | 75 | 96 | -61 | 31 |
| 25200 | 7000 | | -520 | -220 | -77 | 0 | 44 | 70 | -111 | 0 |
| 28800 | 8000 | | -800 | -380 | -175 | -64 | 0 | 64 | -160 | -40 |
| 36000 | 10000 | | -1500 | -800 | -440 | -250 | -125 | 0 | -300 | -160 |
| 45000 | 12500 | | | -1500 | -900 | -560 | -350 | -125 | | -350 |

/34

As can be seen from these values, the total efficiency — even for travel velocities of many hundreds of kilometers per hour — is still so low that, ignoring certain special purposes for which the question of optimization is not important, a far-reaching practical application of rocket propulsion can hardly be considered for any of our customary means of ground transportation.

On the other hand, the situation becomes entirely different if very high travel velocities are taken into consideration. Even at supersonic speeds which are not excessively large, the efficiency is considerably better in a relative sense and attains even extremely favorable values at still higher, almost cosmic travel velocities in the range of thousands of meters per second (up to ten thousand kilometers per hour), as can be seen in Table 2.

It can, therefore, be interpreted as a particularly advantageous encounter of conditions that these high travel velocities are not only possible (no resistance to motion in empty space!) for space vehicles for which the reaction represents the only compatible type of propulsion, but even represent an absolute necessity. How otherwise could those enormous distances of outer space be covered in terms of possible human travel times? A danger, however, that excessively high velocities could perhaps cause harm does not exist, because we are not directly aware whatsoever of velocity per se, regardless of how powerful it may be. After all as "passengers of our Earth," we are continually racing through space in unswerving paths around the sun at a velocity of 30,000 meters per second, while experiencing only the slightest effect. However, the "accelerations" resulting from forced velocity changes are a different matter altogether, as we will see later.

Table 3 permits a comparison to be made more easily among the various travel velocities under consideration here

Table 3 /35

| Kilometers per hour km/hour | Meters per second m/sec | Kilometers per second km/sec |
|---|---|---|
| 5 | 1.39 | 0.00139 |
| 10 | 2.78 | 0.00278 |
| 30 | 8.34 | 0.00834 |
| 50 | 13.9 | 0.0139 |
| 70 | 19.5 | 0.0195 |
| 90 | 25.0 | 0.0250 |
| 100 | 27.8 | 0.0278 |
| 150 | 41.7 | 0.0417 |
| 200 | 55.6 | 0.0556 |
| 300 | 83.4 | 0.0834 |
| 360 | 100 | 0.1 |
| 500 | 139 | 0.139 |
| 700 | 195 | 0.195 |
| 720 | 200 | 0.2 |
| 1000 | 278 | 0.278 |
| 1080 | 300 | 0.3 |
| 1190 | 330 | 0.33 |
| 1800 | 500 | 0.5 |
| 2000 | 556 | 0.556 |
| 2520 | 700 | 0.7 |
| 3000 | 834 | 0.834 |
| 3600 | 1000 | 1 |
| 5400 | 1500 | 1.5 |
| 7200 | 2000 | 2 |
| 9000 | 2500 | 2.5 |
| 10800 | 3000 | 3 |
| 12600 | 3500 | 3.5 |
| 14400 | 4000 | 4 |
| 18000 | 5000 | 5 |
| 21600 | 6000 | 6 |
| 25200 | 7000 | 7 |
| 28800 | 8000 | 8 |
| 36000 | 10000 | 10 |
| 40300 | 11180 | 11.18 |
| 45000 | 12500 | 12.5 |
| 54000 | 15000 | 15 |
| 72000 | 20000 | 20 |

– something which is otherwise fairly difficult due to the /36
difference of the customary systems of notation (kilometers per hour for present day vehicles, meters or kilometers per second for space travel).

## The Ascent

Of the important components which constitute space fight, the ascent, the long-distance travel through outer space, and the return to Earth (the landing), we want to address only the most critical component at this point: the ascent. The ascent represents by far the greatest demands placed on the performance of the propulsion system and is also, therefore, of critical importance for the structure of the entire vehicle.

For implementing the ascent, two fundamental /37
possibilities, the "steep ascent" and "level ascent," result in the type of ascents mentioned in the beginning[4] about the method of movement in the gravity fields of outer space.

In the case of the steep ascent, the vehicle is lifted in at least an approximately vertical direction. During the ascent, the climbing velocity, starting at zero, initially increases continuously thanks to the thrusting force of the reaction propulsion system (Figure 19); more specifically, it increases until a high climbing velocity is attained – we will designate it as the "highest velocity of climbing" – such that now the power can be shut off and the continued ascent, as a "hurl upward," can continually proceed up to the desired altitude only under the effect of the kinetic energy stored in the vehicle in the meantime.

In the case of the level flight, on the other hand, the vehicle is not lifted vertically, but in an inclined (sloped) direction, and it is a matter not so much of

[4] See Page 10.

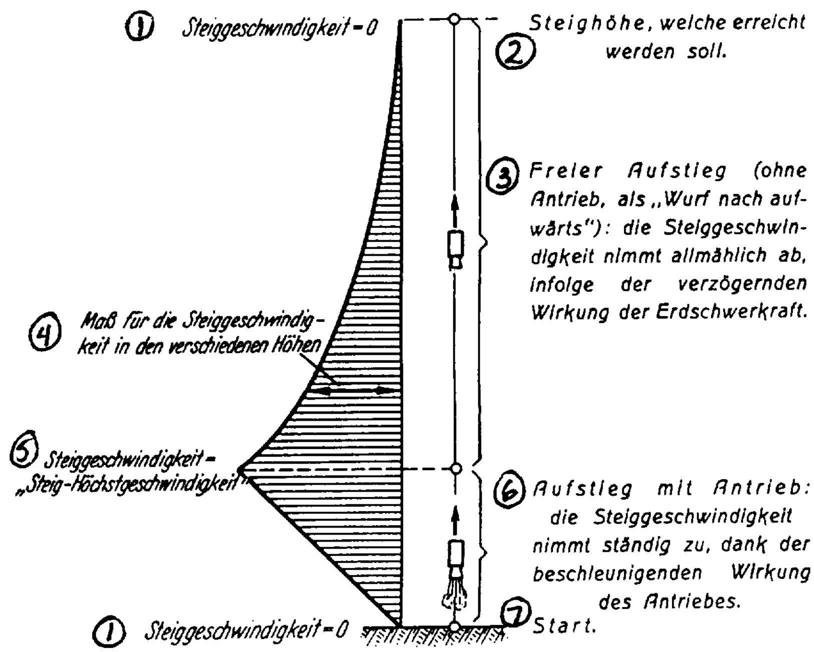


Figure 19. Vertical ascent - "steep ascent" - of a space rocket.

Key: 1. Climbing velocity = 0; 2. Climbing altitude which is supposed to be reached; 3. Free ascent (without power as a "hurl upwards"): the climbing velocity decreases gradually as a result of the decelerating effect of the Earth's gravity.; 4. Scale for the climbing velocity at various altitudes; 5. Climbing velocity = "highest velocity of climbing"; 6. Power ascent: the climbing velocity increases continuously thanks to the accelerating effect of the propulsion system.; 7. Launch.

attaining an altitude but rather more importantly of gaining a horizontal velocity and increasing it until the orbiting velocity necessary for free orbital motion and consequently the "stable state of suspension" are attained (Figures 5 and 20). We will examine this type of ascent in more detail later.

First, however, we want to examine some other points, including the question: How is efficiency behaving during the ascent? Then regardless how the ascent takes place, the

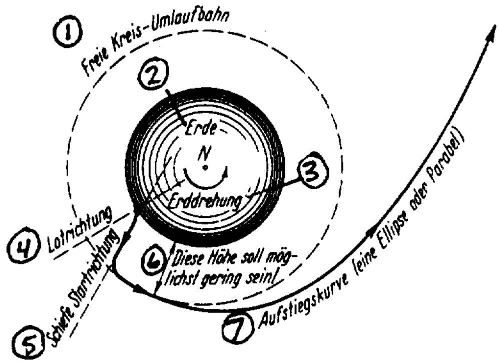


Figure 20. "Level ascent" of a space rocket. The expenditure of energy for the ascent is the lowest in this case.

Key: 1. Free circular orbit; 2. Earth; 3. Earth rotation; 4. Vertical direction; 5. Inclined direction of launch; 6. This altitude should be as low as possible!; 7. Ascent curve (an ellipse or parabola)

required final velocity can only gradually be attained in any case, leading to the consequence that the travel (climbing) velocity of the space rocket will be lower
in the beginning and greater later on (depending on the /38
altitude of the final velocity) than the velocity of repulsion. Accordingly, the efficiency of the reaction must also be constantly changing during the power ascent, because the efficiency, in accordance with our previous definitions, is a function of the specific mutual ratio of the values of the velocities of travel and repulsion (see Table 1, Page 28). Accordingly in the beginning, it will only be low, increasing gradually with an increasing climbing velocity, and will finally exceed its maximum (if the final velocity to be attained is correspondingly large) and will then drop again.

In order to be able to visualize the magnitude of the efficiency under these conditions, the "average efficiency of the reaction" $\eta_{rm}$ resulting during the duration of the propulsion must be taken into consideration. As can be easily seen, this efficiency is a function, on the one hand, of the velocity of repulsion c, which we want to assume as constant for the entire propulsion phase, and, on the other hand, of the final velocity v' finally attained at the end of the propulsion period.

The following formula provides an explanation on this point:

$$\eta_{rm} = \frac{\left(\frac{v'}{c}\right)^2}{e^{\frac{v'}{c}} - 1} \quad [5];$$

---

[5] The average efficiency of the reaction

$$\eta_{rm} = \frac{\text{Energy gained}}{\text{Energy expended}} =$$

$$\frac{\text{Kinetic force of the final mass M at the final velocity v'}}{\text{Kinetic force of the repelling mass } (M_0 - M) \text{ at the velocity of repulsion c:}}$$

$$\eta_{rm} = \frac{\frac{Mv'^2}{2}}{\frac{(M_0 - M)c^2}{2}}.$$

With $M_0 = Me^{\frac{v'}{c}}$ the following results (see Page 50):

$$\eta_{rm} = \frac{Mv'^2}{\left(Me^{\frac{v'}{c}} - M\right)c^2} = \frac{\left(\frac{v'}{c}\right)^2}{e^{\frac{v'}{c}} - 1}.$$

Table 4 was prepared using this formula. /39

Table 4

| Ratio of the final velocity v' to the velocity of repulsion c: v' / c | Average efficiency of the reaction $\eta_{rm}$ during the acceleration phase | |
|---|---|---|
| | $\eta_{rm} = \frac{\left(\frac{v'}{c}\right)^2}{e^{\frac{v'}{c}} - 1}$ | $\eta_{rm}$ in percentages |
| | | 0 |
| 0 | 0 | 18 |
| 0.2 | 0.18 | 44 |
| 0.6 | 0.44 | 58 |
| 1 | 0.58 | 62 |
| 1.2 | 0.62 | 64 |
| 1.4 | 0.64 | **65** |
| **1.59** | **0.65** | 64 |
| 1.8 | 0.64 | 63 |
| 2 | 0.63 | 61 |
| 2.2 | 0.61 | 54 |
| 2.6 | 0.54 | 47 |
| 3 | 0.47 | 30 |
| 4 | 0.30 | 17 |
| 5 | 0.17 | 9 |
| 6 | 0.09 | 4 |
| 7 | 0.04 | |

The table shows the average efficiency of the reaction as a function of the ratio of the final velocity v' attained at the end of the propulsion phase to the velocity of repulsion c existing during the propulsion phase, that is, a function of v'/c. Accordingly by way of example at a velocity of repulsion of c = 3,000 meters per second and for a propulsion phase at the end of which the final velocity of v = 3,000 meters per second is attained (that is, for v'/c = 1), the average efficiency of the reaction would be 58 /40 percent. It would be 30 percent for the final velocity of v = 12,000 meters per second (that is, v'/c = 4), and so on. In the best case (that is, for v'/c = 1.59) in our example, the efficiency would even attain 65 percent for a propulsion phase at a final velocity of v'= 4,770 meters per second.

In any case it can be seen that even during the ascent, the efficiency is generally still not unfavorable despite the fluctuations in the ratio of the velocities of travel and repulsion.

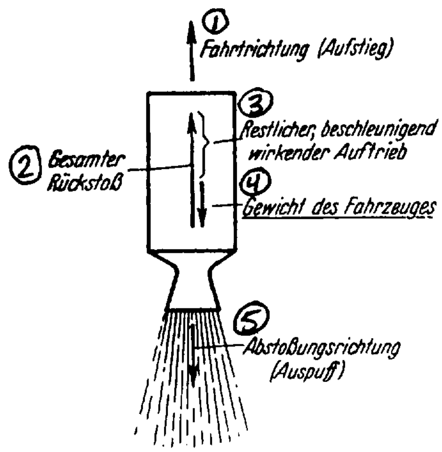


Figure 21. As long as the vehicle has to be supported (carried) by the propulsion system during the ascent, the forward thrust of the vehicle is decreased by its weight.

Key: 1. Direction of flight (ascent); 2. Total reaction; 3. Remaining propulsion functioning as an acceleration; 4. Weight of the vehicle; 5. Direction of repulsion (exhaust).

Besides the efficiency problem being of interest in all cases, a second issue of extreme importance exists especially for the ascent. As soon as the launch has taken place and, thus, the vehicle has lifted off its support (solid base or suspension, water level, launch balloon, etc.), it is carried only by the propulsion system (Figure 21), something – corresponding to the nature of the reaction – which is related to a continual expenditure of energy (fuel consumption). As a result, that amount of fuel required for the lift-off, is increased by a further, not insignificant value. This condition lasts only until –

depending on the type of ascent, steep or level – either the necessary highest climbing velocity or the required horizontal orbiting velocity is attained. The sooner this happens, the shorter the time duration during which the vehicle must be supported by the propulsion system and the lower the related fuel consumption will be. We see then that a high velocity must be attained as rapidly as possible during the ascent. /41

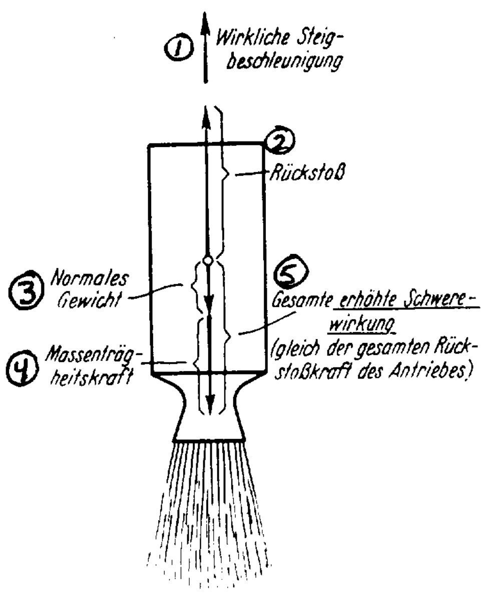


Figure 22. During the duration of propulsion, forces of inertia are activated – due to the acceleration of the vehicle (increase in velocity) caused by propulsion – in the vehicle; the forces are manifested for the vehicle similar to an increase in gravity.

Key: 1. Actual acceleration of climb; 2. Reaction; 3. Normal weight; 4. Force of inertia; 5. Total increased effect of gravity (equals the total reaction force of the propulsion system).

However, a limit is soon set in this regard for space ships which are supposed to be suitable for transporting people. Then, the related acceleration always results in the release of inertial forces during a forced velocity increase (as in this case for the propulsion system) and not caused solely by the free interaction of the inertial forces. These forces are manifested for the vehicle during the ascent like an increase in gravity (Figure 22) and may not exceed a certain level, thus ensuring that the passengers do not suffer any injuries. Comparison studies carried out by Oberth as well as by Hohmann and previous experiences in aviation (e.g., during propeller flights) indicate that an actual acceleration of climb up to 30 m/sec$^2$ may be acceptable during a vertical ascent. In this case during the duration of propulsion, the vehicle and its contents would be subjected to the effect of the force of gravity of four times the strength of the Earth's normal gravity. Do not underestimate what this means! Then, this means nothing less than that the feet would have to support almost four times the customary body weight. Therefore, this ascent phase, lasting only a few minutes, can be spent by the passengers in nothing other than in a lying-down position, for which purpose Oberth anticipated hammocks.

Taking into account the limitations in the magnitude of the acceleration, that highest climbing velocity, which would be required for the total separation from the Earth, can be attained only at an altitude of approximately 1,600 km with manned space ships during a vertical ascent. The rate of climb is then around 10,000 meters per second and is attained after somewhat more than 5 minutes. The propulsion system must be active that long. In accordance with what was stated previously, the vehicle is supported (carried) by the propulsion system during this time, and furthermore the resistance of the Earth's atmosphere still has to be overcome. Both conditions cause, however, an increase of the energy consumption such that the entire energy expenditure necessary for the ascent up to the total separation from the Earth finally becomes just as large as if an ideal highest velocity of around 13,000 meters per second would have to be imparted in total to the vehicle. Now this velocity (not the actual highest climbing velocity of 10,000 meters per second) is critical for the amount of the fuels required.

Somewhat more favorable is the case when the ascent does not take place vertically, but in an inclined curve; in particular, when during the ascent the vehicle in addition strives to attain free orbital motion around the Earth as close to its surface as practical, taking the air drag into account (perhaps at an altitude of 60 to 100 km above sea level). And only then — more specifically, through a further increase of the orbiting velocity — the vehicle works its way up to the highest velocity necessary for attaining the desired altitude or for the total separation from the Earth ("level ascent," Figure 20).

/43

The inclined direction of ascent has the advantage that the Earth's gravity does not work at full strength against the propulsion system (Figure 23), resulting, therefore, in a greater actual acceleration in the case of an equal ideal acceleration (equal propulsion) — which, according to what has been previously stated, is restricted when taking the well-being of the passengers into account. The greater acceleration results in the highest velocity necessary for the ascent being attained earlier.

However, the transition into the free orbital motion as soon as possible causes the vehicle to escape the Earth's gravity more rapidly than otherwise (more specifically, through the resulting premature effect of the centrifugal force).

Both conditions now cause the duration to be shortened during which the vehicle must be carried by the propulsion system and saving on the expenditure of energy as a result. Consequently, the ideal highest velocity to be imparted to the vehicle for totally separating from the Earth is only

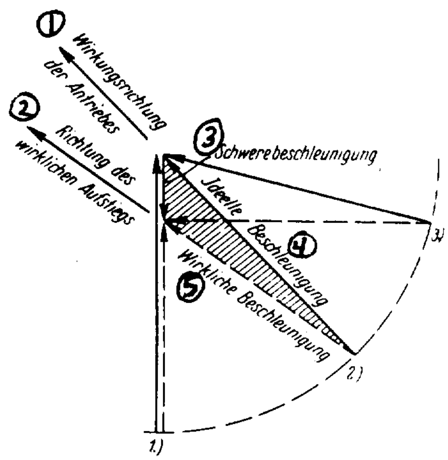


Figure 23. Acceleration polygon for: 1.) vertical ascent, 2.) inclined ascent, 3.) horizontal ascent.
It can clearly be seen that the actual acceleration from 1.) to 3.) becomes greater and greater, despite a constant ideal acceleration (force of the propulsion system). (The acceleration polygon for 2.) is emphasized by hatched lines.)

Key: 1. Direction of the effect of the propulsion system; 2. Direction of the actual ascent; 3. Acceleration of gravity; 4. Ideal acceleration; 5. Actual acceleration.

around 12,000 meters per second when employing this ascent maneuver, according to Oberth. According to the author, we should come closest to the actually attainable velocity in practice when assuming an ideal highest velocity of approximately 12,500 meters per second.

Regardless of how the ascent proceeds, it requires in /44
every case very significant accelerations, such that the vehicle attains a velocity of a projectile at an altitude of several kilometers. This condition – in the thick density of the deepest layers of air closest to the surface of the Earth – results in the air drag reaching very undesirable high values in the very initial phases of the ascent, something which is particularly true for unmanned space

rockets. Then, considerably greater accelerations of climb can be employed in unmanned vehicles than in manned ones because health is not a consideration for the former.

To come to grips with this disadvantage, the launch will take place from a point on the Earth's surface as high as possible, e.g., from a launch balloon or another air vehicle or from a correspondingly high mountain. For very large space ships, however, only the latter option is possible due to its weight, even though in this case the launch would preferably be carried out at a normal altitude.

## General Comments about the Structure of the Space Rocket

Corresponding to the variety of purposes and goals possible for space ship flight, the demands placed on the vehicle will also be of the most varied type on every trip. For space ships, it will, therefore, be demonstrated as necessary to make the structure of the vehicle compatible with the uniqueness of the respective trip in a considerably more comprehensive extent than for the means of transportation known to date. Nevertheless, the important equipment as well as the factors critical for the structure will be common for all space ships.

The external form of a space vehicle will have to be similar to that of a projectile. The form of a projectile is best suited for overcoming air drag at the high velocities attained by the vehicle within the Earth's atmosphere (projectile velocity, in accordance with previous statements!).

Fundamental for the internal structure of a rocket /45 vehicle is the type of the fuel used. The following requirements are placed on it:

1. That it achieves an exhaust velocity as high as possible because the necessity was recognized previously for

a repulsion velocity of the accelerating masses as high as possible.

2. That it has a density as high as possible (high specific weight), so that if at all possible a small tank would suffice for storing the necessary amount of weight. Then, on the one hand, the weight of the tank is decreased and, on the other hand, the losses due to air drag also become smaller.

3. That its combustion would be carried out in a harmless way compatible for generating a constant forward thrust.

4. That handling it would cause as few difficulties as possible.

Any type of gunpowder or a similar ingredient (a solid fuel), similar to fireworks rockets, would be the most obvious to use. The structure of the vehicle could then be relatively simple, similar to that of the familiar fireworks rocket. In this manner for various special tasks, it would, no doubt, be possible to build serviceable equipment which, however, primarily paves the way for warfare, a point that will be discussed subsequently in the following.

However for purposes of traveling in outer space, especially when the transportation of people is also supposed to be made possible, using liquid fuels should by far offer more prospects for development options, despite the fact that considerable engineering problems are associated with these types of fuels; this point will be discussed later.

The most important components of a space ship for liquid fuels are as follows: the propulsion equipment, the tanks for the fuels, the passenger compartment and the means of landing.

The propulsion equipment is the propulsion motor of the /46
space ship. The reaction is produced in it and as a result the on board energy stored in the fuels is converted into

forward thrust. Concerning this point, it is necessary for the most part to load the fuel into an enclosed space in order to burn it there and then to let it escape (exhaust) towards the rear. Two basic possibilities exist for this:

1. The same compressed strain continuously exists in the combustion chamber. In injecting the fuel, it must, therefore, be pressed into the combustion chamber by overcoming this pressure. We will designate motors of this type as "constant pressure rocket motors."

2. The combustion proceeds in such a fashion that the combustion chamber is continuously reloaded in a rapid sequence with fuel, repeatedly ignited (detonated) and allowed to escape completely every time. In this case, injecting the fuel can also take place without an overpressure. Motors of this type we will designate as "detonation (or explosion) rocket motors."

The main components of the constant pressure rocket motors are the following: the combustion chamber, also called the "oven", and the "nozzle" located downstream from the combustion chamber (Figure 24), whose components can be designed in varying quantities depending on the requirements.

The operating characteristics are as follows: the fuel (fuel and oxygen) is pressed into the oven in a compatible state by means of an appropriate overpressure and is burned there. During the combustion, its chemically bonded energy is converted into heat and – in accordance with the related temperature increase – also into a compressed strain of the gases of combustion generated in this manner and inclosed in the oven. Under the effect of this pressure, the gases of combustion escape out the nozzle and attain as a result that velocity previously designated as "exhaust velocity." The acceleration of the gas molecules associated with this imparting of velocity results, however, in the occurrence of /47
counteracting forces of inertia (counter pressure, similar

to pushing away an object[6]!), whose sum now produces that force of "reaction" (Figure 24) which is supposed to power the vehicle forward in the same fashion as has already been discussed in an introductory sense[7]. The forward thrust is obtained via heat, pressure, acceleration and reaction from the energy chemically bonded in the fuels.

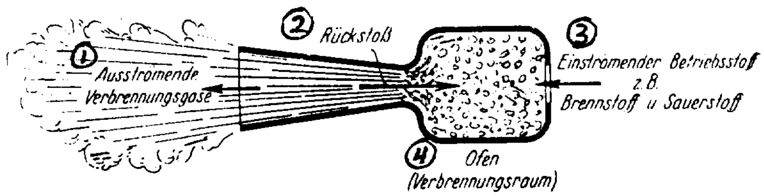


Figure 24. The combustion chamber or "oven" and the "nozzle", the main components of the constant pressure rocket motor.

Key: 1. Escaping gases of combustion; 2. Reaction; 3. Fuel flowing in, e.g., fuel and oxygen; 4. Oven (combustion chamber).

So that this process is constantly maintained, it must be ensured that continually fresh fuel is injected into the oven. To this end, it is, however, necessary, as has been stated previously, that the fuels exhibit a certain overpressure compared to the oven. If an overpressure is supposed to be available in the tanks, then they would also have to have an appropriate wall thickness, a property, however, which for larger tanks could presents problems. Otherwise, pumps will have to be carried on board in order to bring the fuels to the required pressure.

Furthermore, related equipment, such as injectors, evaporators and similar units are required so that the on board liquid fuels can also be converted into the state

---

[6] See Pages 18 and 19, Figure 12.

[7] See Page 19.

suitable for combustion. Finally, the vehicle designers must also make provisions for sufficient cooling of the oven and nozzle, for control, etc.

The entire system has many similarities to a constant pressure gas turbine. And similar to that case, the not so simple question also exists in this case of a compatible material capable of withstanding high temperatures and of corresponding cooling options for the combustion chamber and nozzle. On the other hand, the very critical issue of a compressor for a gas turbine is not applicable for the rocket motor. /48

Similarly, the detonation rocket motor exhibits many similarities to the related type of turbine, the detonation (explosion) gas turbine. As with the latter, the advantage of a simpler fuel injection option must also be paid for in this case by a lower thermal efficiency and a more complicated structure.

Which type of construction would have the advantage can only be demonstrated in the future development of the rocket motor. Perhaps, this will also be, in part, a function of the particular special applications of the motor.

It would not suffice alone to have only a motor functioning in completely empty space. We must still have the option of carrying on board into outer space the necessary amounts of energy in the form of fuels. Consequently, we are faced with a critically important question: the construction of the tanks for the fuels. /49

How large, in reality, is the amount of fuel carried on board? We know that the propulsion of the rocket vehicle occurs as a result of the fact that it continually repeals towards the rear parts of its own mass (in our case, the fuels in a gasified state). After the propulsion system has functioned for a certain time, the initial mass of the vehicle (that is, its total mass in the launch-ready state) will have been decreased to a certain final mass by the

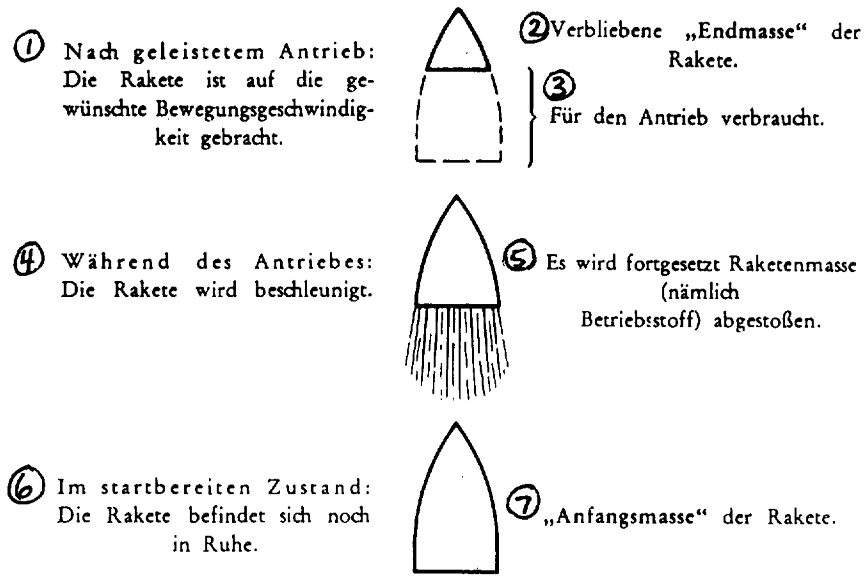


Figure 25.

Key: 1. Following a completed propulsion phase: The rocket is brought to the desired velocity of motion; 2. Remaining "final mass" of the rocket.; 3. Consumed for the propulsion; 4. During the propulsion phase: The rocket is accelerated; 5. A rocket mass (namely, the fuel) is continually repelled.; 6. In the launch-ready state: The rocket is at rest.; 7. "Initial mass" of the rocket.

amount of fuel consumed (for attaining repulsion) during this time (Figure 25). This final mass represents, therefore, the total load which was transported by means of the amount of fuel consumed and which consists of the payload, the vehicle itself and the remaining amounts of fuel.

The question is now as follows (Figure 26): How large must the initial mass $M_0$ be when a fixed final mass M is supposed to be brought to a velocity of motion v at a constant exhaust velocity c? The rocket equation provides an answer to this question: $M_0 = 2.72^{v/c}M$.

According to the above, the initial mass $M_0$ of a space rocket is calculated as shown below. This mass should be

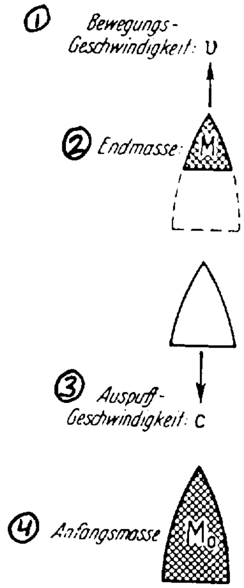


Figure 26.

Key: 1. Velocity of motion; 2. Final mass; 3. Exhaust velocity; 4. Initial mass.

According to the above, the initial mass $M_0$ of a space rocket is calculated as shown below. This mass should be capable of imparting the previously discussed[8] ideal highest climbing velocity of 12,500 meters per second, approximately necessary for attaining complete separation from the Earth.

/50

$M_0$ = 520 M, for c = 2,000 meters per second
$M_0$ = 64 M, for c = 3,000 meters per second
$M_0$ = 23 M, for c = 4,000 meters per second
$M_0$ = 12 M, for c = 5,000 meters per second.

This implies the following: for the case that the exhaust velocity c is, by way of example, 3,000 meters per second, the vehicle, at the beginning of the propulsion phase, must be 64 times as heavy with the fuels necessary

[8] See Page 44.

for the ascent than after the fuels are consumed. Consequently, the tanks must have a capacity to such an extent that they can hold an amount of fuel weighing 63 times as much as the empty space rocket, including the load to be transported, or expressed differently: an amount of fuel which is 98.5 percent of the total weight of the launch-ready vehicle.

An amount of fuel of 22 times the weight would also suffice if the exhaust velocity is 4,000 meters per second and only 11 times if the exhaust velocity increases up to 5,000 meters per second. Ninety-six and/or 92 percent of the total weight of the launch-ready vehicle is allocated to the fuel.

As has been frequently emphasized, the extreme importance of a repulsion (exhaust) velocity as high as possible can clearly be recognized from these values. (The velocity is the expression of the practical energy value of the fuel used!)

However, only those rockets which are supposed to be capable of imparting the highest climbing velocity necessary for the total separation from the Earth must have a fuel capacity as large as that computed above. On the other hand, the "ratio of masses" (ratio of the initial to the final mass of the rocket: $M_0$ / M) is considerably more favorable for various types of applications (explained later) in which lower highest velocities also suffice.

In the latter cases from a structural engineering point /51
of view, fundamental difficulties would not be caused corresponding to the demands vis-a-vis the fuel capacity of the vehicle and/or of the tanks. By way of example, a space rocket, which is supposed to attain the final velocity of v = 4,200 meters per second at an exhaust velocity of c = 3,000 meters per second, would have to have a ratio of masses of $M_0$ / M = 4, as results from the rocket equation. That is, the rocket would have to be capable of storing an

amount of fuel which is 75 percent of its total launch weight, a capability which can certainly be achieved from a structural engineering point of view.

Nevertheless, space rockets of this nature, which can carry on board the amounts of fuel necessary for the complete separation from the Earth (according to what has already been stated, the amounts of fuel are 98.5 percent of the launch weight at an exhaust velocity of c = 3,000 meters per second), would, for all practical purposes, not be easily realized. Fortunately, there is a trick making it possible to circumvent this structural difficulty in a very simple manner: the so-called staging principle which both Goddard and Oberth recognized independently of one another as a fundamental principle of rocket technology.

In accordance with this principle, the desired final velocity need not be attained with a single rocket; but rather, the space rocket is divided into multiple units (stages), each one always forming the load for the next largest unit. If, for example, a three-stage space rocket is used, then it consists of exactly three subrockets: the subrocket 3 is the smallest and carries the actual payload. It forms (including this payload) the load of subrocket 2 and the latter again (including subrocket 3 and its payload) the load of subrocket 1. During ascent, subrocket 1 functions first. As soon as this stage is lifted, its empty shell is decoupled and subrocket 2 starts to function. When it is spent, it also remains behind and now subrocket 3 functions until the desired final velocity is attained. Only the latter arrives at the destination with the payload.

Because the final velocities of three subrockets are /52
additive in this process, each individual one must be able to generate only 1/3 of the total required final velocity.

In the case of a 3-stage space rocket, which is supposed to attain the highest climbing velocity of 12,500 meters per second necessary for the total separation from the Earth, only a final velocity to be attained of around 4,200 meters per second, would consequently be allocated to each subrocket. For that, however, the fuel capacity, certainly implementable from an engineering point of view, of 75 percent (ratio of masses $M_0$ / M = 4) suffices, as we determined previously, at an exhaust velocity of c = 3,000 meters per second, for example. If the individual subrockets can, however, be manufactured, then no doubt exists about the possibility of erecting the complete rocket assembled from all subrockets.

As a precautionary measure, let's examine the absolute values of the rocket masses or rocket weights resulting from the above example. Assume a payload of 10 tons is to be separated from the Earth; the individual subrockets may be built in such a fashion that their empty weight is equally as large as the load to be transported by them. The weights of the subrockets in tons result then as follows:

| Subrocket | Load | Empty weight | Final weight M | Initial weight $M_0$ |
|---|---|---|---|---|
| 3 | 10 | 10 | 10 + 10 = 20[1] | 4 x 20 = 80[2] |
| 2 + 3 | 80 | 80 | 80 + 80 = 160 | 4 x 160 = 640 |
| 1 + 2 + 3 | 640 | 640 | 640 + 640 = 1280 | 4 x 1280 = 5120 |

1) The final weight M is equal to the empty weight plus the load when the rocket – as in this case – functions until its fuel is completely consumed.

2) The initial weight $M_0$ is, in this case, equal to 4 times the final weight M because, as has been stated previously in our example, each subrocket approaches the ratio of masses (weights) $M_0$ / M = 4.

The initial weight of the total space rocket consisting of 3 stages would be 5,120 tons, a number which is not particularly impressive, considering the fact that technology is capable of building, for example, an ocean liner weighing 50,000 tons. /53

In this fashion – by means of the staging principle – it would actually be possible to attain any arbitrary final velocity, in theory at least. For all practical purposes in this regard, fixed limitations will, of course, result, in particular when taking the absolute values of the initial weights into consideration. Nevertheless an irrefutable proof is inherent in the staging principle to the effect that it would be fundamentally possible to build compatible space rockets for separating from the Earth even with the means available today.

Having said that, it does not imply that the staging principle represents the ideal solution for constructing space rockets in the described form, because it leads to an increase of the dead weight and as a result of the fuel necessary for transportation. This, however, is not now a critical point. Initially, we are only concerned with showing "that it is possible in the first place." Without a doubt every type of space rocket construction, regardless of which one, will have to customize the fundamental concept expressed in the staging principle: during the duration of propulsion – for the purpose of saving fuel – every part of the vehicle, which has become unnecessary, must be immediately released (jettisoned) in order not uselessly to carry dead weight and, at the same time, to have to accelerate further with the remaining weight. It is assumed, of course, that we are dealing with space rockets which are supposed to attain greater final velocities.

From a structural engineering point of view, we do not want to hide from the fact that certainly quite a few difficulties will arise to do justice to the still

significant demands imposed on the capacity of the fuel tanks – despite the staging principle. In this regard, it will be necessary in part to use construction methods deviating fundamentally from the customary ones, because all parts of the vehicle, in particular the tanks, must be made as light-weight as possible. Nevertheless, the tanks must /54
have sufficient strength and stiffness in order to be able to withstand both the pressure of mass and atmospheric pressure during the ascent, taking into account that many of the usual metals become brittle and, therefore, lose strength at the extreme lower temperatures to which the tanks are mainly exposed.

Moreover in a space ship, a passenger compartment (passenger cell) must exist for housing the pilot and passengers and for storing supplies of the life-giving necessities and other equipment, as well as for storing freight, scientific devices for observations, etc. The compartment must be air-sealed and must have corresponding precautionary measures for artificially supplying air for breathing and for maintaining a bearable temperature. All equipment necessary for controlling the vehicle are also stored in the compartment, such as manual controls for regulating the propulsion system; recorders for time, acceleration, velocity, and path (altitude); and for determining the location, equipment for maintaining the desired direction of flight, and similar functions. Even space suits (see the following), hammocks, etc. must be available.

Finally, the very important aids for landing, such as parachutes, wings, etc. also belong to the equipment configuration of a space ship.

## Recommendations To Date

The following are the various recommendations made to date for the practical solution of the space flight problem:

Professor Goddard uses a smokeless powder, a solid substance, as a fuel for his space rockets. He has not described any particular device, but recommends only in general packing the powder into cartridges, similar to a machine gun, and injecting it automatically into the combustion chamber. The entire rocket should be composed of individual subrockets which are jettisoned one after the other during the ascent, as soon as they are spent, with the exception of that subrocket containing the payload, and it /55
alone reaches the destination. First of all, he intends to let unmanned devices climb to an altitude of several hundred kilometers. Subsequently, he also wants to try to send up an unmanned rocket to the moon equipped only with several kilograms of luminous powder. When landing on the moon, the light flare is supposed to flash, something which could then be detected with our large telescopes, thus verifying the success of the experiment. Reportedly, the American Navy is greatly interested in Goddard's devices.

The results of practical preliminary experiments previously published and conducted by Goddard are very valuable; the means for carrying out these experiments were provided to him in a very generous manner by the famous Smithsonian Institution in Washington. He was able to attain exhaust velocities up to 2,434 meters per second with certain types of smokeless powder when appropriately shaping and designing the nozzles. During these experiments, he was successful in utilizing 64.5 percent of the energy chemically bonded in the powder, that is, to convert it into a kinetic force of the escaping gases of combustion. The result agrees, for the most part, with the experiences of ballistics, according to which approximately 2/3 of the energy content of the powder can be utilized, while the remainder is allocated to the heat carried by the exhaust gases and is lost, as a result. Perhaps, the efficiency of the oven and nozzle will also increase by several orders during further engineering improvements, to approximately 70 percent.

Therefore, an "internal efficiency" of approximately 60 percent could be expected in total for the entire propulsion equipment – the rocket motor – after taking into consideration the additional losses caused by the various auxiliary equipment (such as pumps and similar devices) as well as by other conditions. This is a very favorable result considering that the efficiency is hardly more than 38 percent even for the best thermal engines known to date.

It is a good idea to distinguish the internal /56
efficiency just considered from that addressed previously: the efficiency of the reaction[9], which could also be designated as the "external efficiency" of the rocket motor to distinguish it from the former. Both are completely independent from one another and must be considered at the same time in order to obtain the total efficiency of the vehicle (which is exactly the product of the internal and external efficiency). As an example, the values of the efficiency for benzene as the fuel are listed in Column 3 of Table 2, Page 32.

*

Differing from Goddard, Professor Oberth suggests using liquid fuels, primarily liquid hydrogen and additionally alcohol, both with the amounts of liquid oxygen necessary for their combustion.

---

[9] See Page 26.

The hydrogen-oxygen mixture – called detonating gas – has the highest energy content (3,780 calories per kilogram compared to approximately 1,240 for the best smokeless powder) vis-a-vis the weight for all known substances. Accordingly, it yields by far the highest exhaust velocity. Oberth figured being able to attain approximately 3,800 - 4,200 meters per second. If we were successful in utilizing the energy chemically bonded in the detonating gas up to the theoretically highest possible limit, then its exhaust velocity could even climb to over 5,000 meters per second. The resulting gas of combustion is steam.

Unfortunately, the difficulty of carrying and using the gas in a practical sense is a big disadvantage compared to the advantage of its significant energy capacity and as a result relatively high exhaust velocity, thanks to which the detonating gas would in theory appear to be by far the most suitable fuel for space rockets. Storing hydrogen as well as oxygen in the rocket is possible then only in the liquefied state for reasons of space.

However, the temperature of the liquid oxygen is - 183° /57
and that of the liquid hydrogen only - 253° Celsius. It is clear that this condition must considerably complicate the handling, ignoring the unusual requirements being imposed on the material of the tanks as a result. Additionally, the average density (specific weight) of the detonating gas is very low even in a liquefied state such that relatively large tanks are necessary for storing a fixed amount of the weight of the gas.

In the case of alcohol, the other fuel recommended by Oberth, these adverse conditions are partially eliminated, but cannot be completely avoided. In this case, the oxygen necessary for combustion must also be carried on board in the fluid state. According to Oberth, the exhaust velocity is approximately 1,530 - 1,700 meters per second for alcohol and is considerably lower than for hydrogen. Instead it has a greater density, however.

Due to these properties, Oberth uses alcohol together with liquid oxygen as a fuel for the initial phase of the ascent, because the resistance of the dense layers of air near the Earth's surface must be overcome during the ascent. Oberth interpreted a large cross-sectional loading (i.e., the percentage of the total weight of a projectile allocated to 1 $cm^2$ of the air drag cross section of a projectile) as advantageous even for rockets and recommended, besides other points: "to increase the ratio of masses at the expense of the exhaust velocity"[10]. This is, however, attained when alcohol and oxygen are used as a fuel.

Oberth's space rocket has, in general, the external /58
shape of a German S-projectile and is composed of individual subrockets which are powered either with hydrogen and oxygen (hydrogen rocket) or with alcohol and oxygen (alcohol rocket).

Oberth also described in more detail two examples of implementing his space vehicle. Of the two, one is a smaller, unmanned model, but equipped with the appropriate recording instruments and is supposed to ascend and perform research on the higher and highest layers of air. The other one is a large space ship designed for transporting people.

The smaller model (Figure 27) consists of a hydrogen rocket which is inserted into the forward part of a considerably larger alcohol rocket. Space for storing the

---

[10] However, we can not support this suggestion, as must be particularly emphasized in the present case. The suggestion can hardly be tenable because it is based on the conception that the concept of the "cross sectional loading" familiar to ballistics could also be employed in this case. In our opinion, the latter is not, however, easily acceptable; the rocket moving forward with propulsion is essentially subjected to other mechanical conditions than is the oscillating projectile.

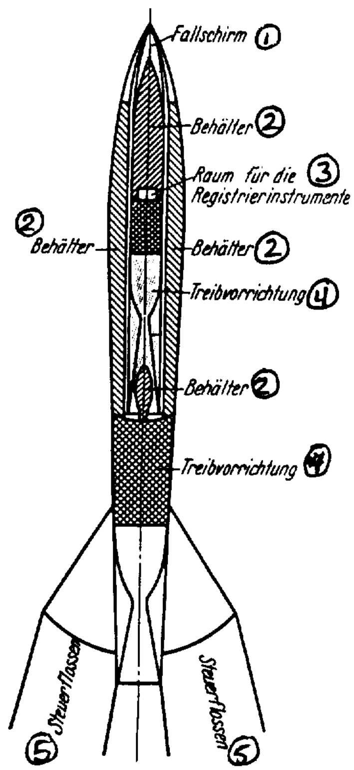


Figure 27. A longitudinal cross section through the main rocket of Oberth's small rocket model is shown schematically. The hydrogen rocket (sketched in gray) is inserted in the forward part of the alcohol rocket.

Key: 1. Parachute; 2. Tank; 3. Space for the recording instruments; 4. Propulsion equipment; 5. Control fins.

recording instruments is located below the tank of the hydrogen rocket. At the end of the alcohol rocket, adjustable fins are arranged which are supposed to stabilize and to control the vehicle. The entire apparatus is 5 meters long, measures 56 cm in diameter and weighs 544 kg in the launch-ready state.

Furthermore, a so-called "booster rocket" (Figure 28) is planned which is 2 meters high, 1 meter in diameter and weights 220 kg in the launch-ready state.

Launching takes place from dirigibles starting at an /59
altitude of 5,500 meters (Figure 29). Initially by means of

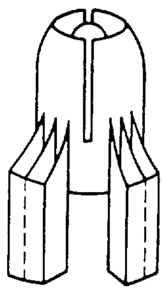

Figure 28. The booster rocket of Oberth's small rocket model.

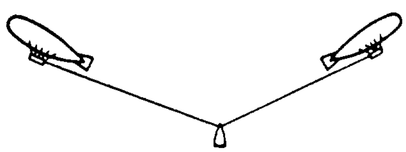

Figure 29. Launching the rocket from dirigibles, according to Oberth.

the booster rocket, which remains behind, the main rocket is lifted to an altitude of 7,700 meters and then brought to an initial velocity of 500 meters per second (Figure 30). Now, the rocket activates automatically: first the alcohol rocket and, after it is spent and decoupled, then the hydrogen rocket. Fifty-six seconds after the launch, a highest climbing velocity of 5,140 meters per second is attained, which suffices for the sole remaining hydrogen rocket, now without power, to reach a final altitude of approximately 2,000 km in a free ascent. The return to Earth takes place by means of a self-opening parachute stored in the tip of the hydrogen rocket.

In the case of the second model, the large rocket space ship designed for transporting people (Figure 31), the extreme forward part of the vehicle consists of a hydrogen rocket set atop an alcohol rocket oriented towards the rear. The passenger compartment designed for passengers, freight,

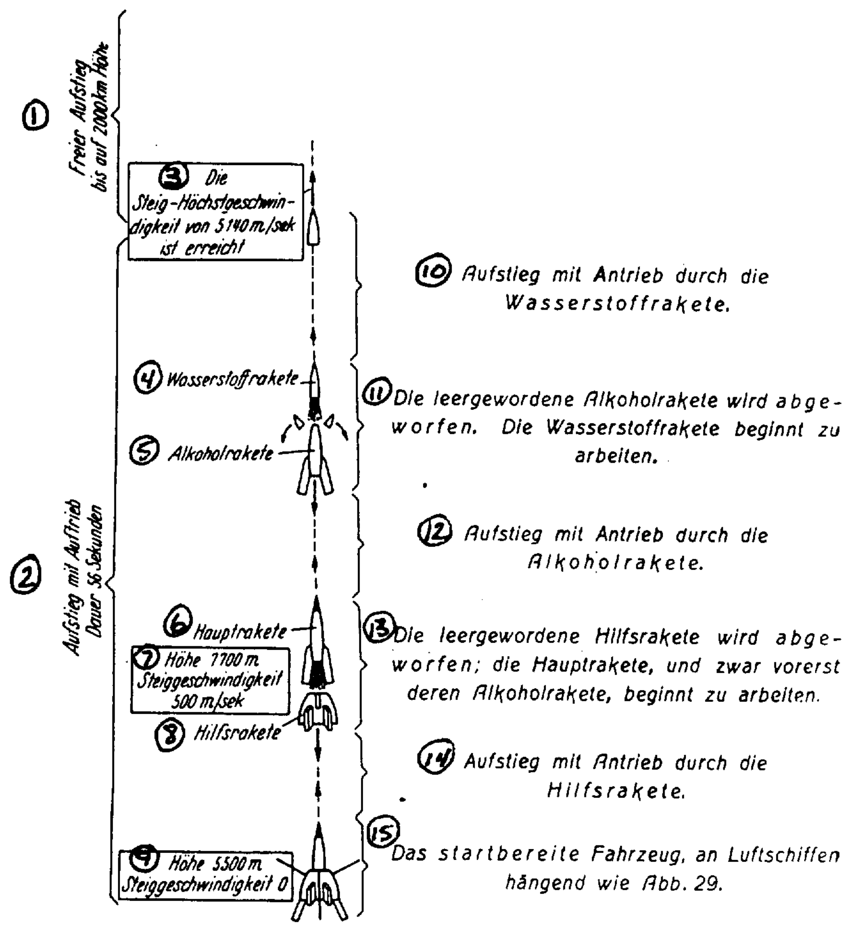


Figure 30. The ascent of Oberth's small (unmanned) rocket model.

Key: 1. Free ascent up to an altitude of 2,000 km; 2. Power ascent lasting 56 seconds; 3. The highest climbing velocity of 5,140 m/sec is attained; 4. Hydrogen rocket; 5. Alcohol rocket; 6. Main rocket; 7. Altitude of 7,700 m, climbing velocity of 500 m/sec; 8. Booster rocket; 9. Altitude of 5,500 m, climbing velocity of 0; 10. Power ascent by the hydrogen rocket; 11. The empty alcohol rocket is jettisoned. The hydrogen rocket starts to function; 12. Power ascent by the alcohol rocket; 13. The empty booster rocket is jettisoned; the main rocket, in particular, its alcohol rocket starts to function for the time being; 14. Power ascent by the booster rocket; 15. The launch-ready vehicle, suspended from dirigibles, as shown in Figure 29.

etc. and equipped with all control devices, is located in the forward part of the hydrogen rocket. The parachute is stored above it. Towards the front, the vehicle is sealed by a metal cap compatible to the external shape of a projectile, which later is jettisoned as unnecessary ballast along with the alcohol rocket at the same time (Figure 32), because the Earth's atmosphere is left behind at this point, meaning no longer any air drag to overcome. In this case, stabilizing and controlling takes place not by means of fins, but by appropriately throttling the external nozzles.

/60

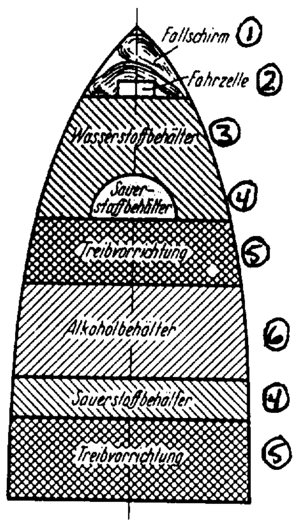


Figure 31. A longitudinal cross section of Oberth's large rocket for transporting people is shown schematically. The hydrogen rocket (sketched in gray) is set atop the alcohol rocket.

Key: 1. Parachute; 2. Passenger compartment; 3. Hydrogen tank; 4. Oxygen tank; 5. Propulsion equipment; 6. Alcohol tank.

For this model, launching is performed over the ocean. In this case, the alcohol rocket activates first. It brings the vehicle up to a climbing velocity of 3,000 - 4,000 meters per second, where it is decoupled and left behind (Figure 32), and the hydrogen rocket begins to function in order to impart to the vehicle the necessary highest climbing velocity or, if necessary, also a horizontal orbital velocity. A space ship of this nature, designed for /61 transporting an observer, would, according to Oberth's data, weigh 300 t in the launch-ready state.

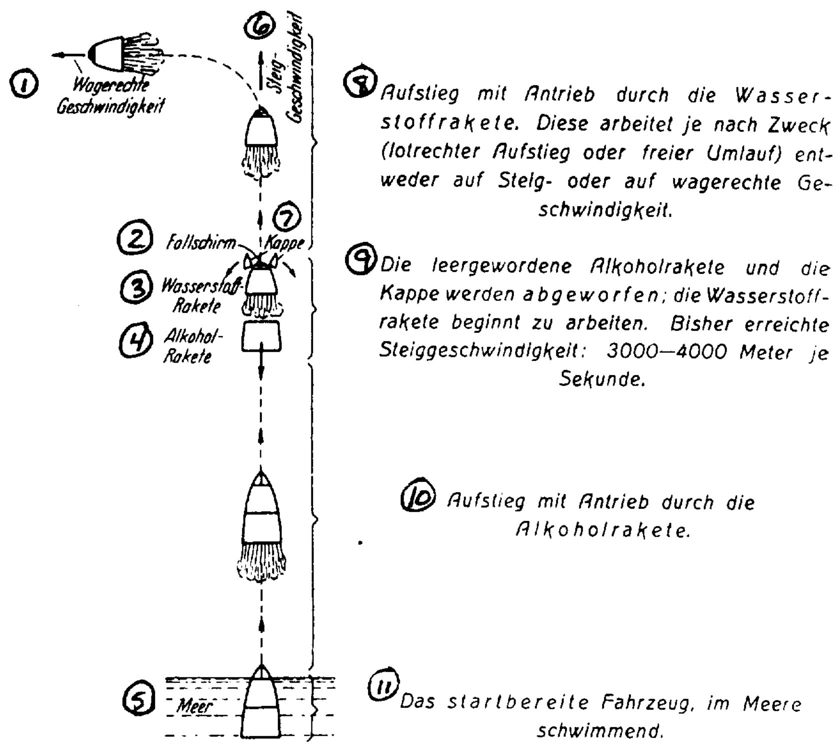


Figure 32. The ascent of Oberth's larger (manned) rocket model.

Key: 1. Horizontal velocity; 2. Parachute; 3. Hydrogen rocket; 4. Alcohol rocket; 5. Ocean; 6. Climbing velocity; 7. Cap; 8. Power ascent by the hydrogen rocket. Depending on the purpose (vertical ascent or free orbiting), this rocket operates either at a climbing velocity or at a horizontal velocity; 9. The empty alcohol rocket and the cap are jettisoned; the hydrogen rocket starts to operate. The climbing velocity attained up to this point is 3,000 to 4,000 meters per second; 10. Power ascent by the alcohol rocket; 11. The launch-ready vehicle floating in the ocean.

In both models, every one of the subrockets is independent; each has, therefore, its own propulsion equipment as well as its own tanks. To save weight, the latter are very thin-walled and obtain the necessary stiffness through pressure filling, that is, by the existence of a correspondingly large internal overpressure, similar to non-rigid dirigibles. When draining the contents, this overpressure is maintained by evaporating the remaining liquid. The oxygen tank is made of copper and the hydrogen tank of lead, both soft metals, in order to prevent the danger of embrittlement caused by the extreme low temperatures discussed previously.

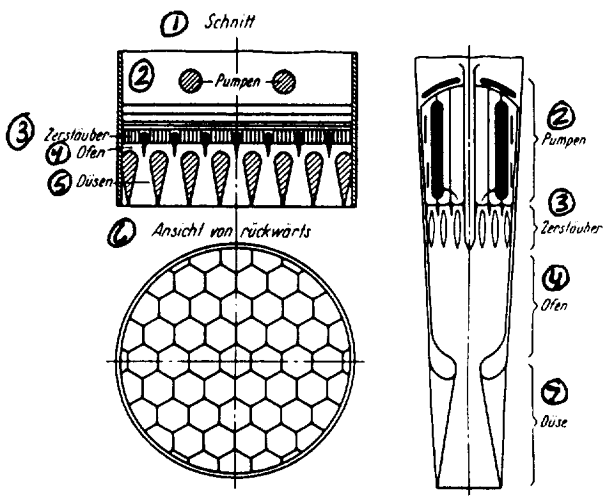


Figure 33. The propulsion equipment of Oberth's rocket:

right: the small model. The oven discharges into only one nozzle.
left: the large model. A common oven discharges into many nozzles distributed in a honeycombed fashion.

Key: 1. Sectional view; 2. Pumps; 3. Injectors; 4. Oven; 5. Nozzles; 6. View from the rear; 7. Nozzle.

The propulsion equipment is located in the rear part of each rocket (Figure 33). For the most part, that equipment consists of the oven and one or more thin sheet metal escape nozzles connected to the oven, as well as various auxiliary equipment necessary for propulsion, such as injectors and similar devices. Oberth uses unique pumps of his own design to bring the fuels to the overpressure necessary for injecting into the oven. Shortly before the combustion, the oxygen is gasified, heated to 700° and then blown into the oven, while the fuel is sprayed automatically into the hot oxygen stream in a finely dispersed state. Arrangements are made for appropriately cooling the oven, nozzles, etc.

It must be obvious how small the passenger compartment designed for the payload is in comparison to the entire vehicle, consisting in substance only of the tanks. This becomes understandable, however, considering the fact that the amounts of fuel previously calculated with the rocket equation[11] and necessary for the ascent constitute approximately 20 to 80 percent of the total load (weight of the vehicle, remaining fuel and payload)! /62

However, the cause for this enormous fuel requirement lies not in an excessively insufficient utilization of the fuels, caused perhaps by a deficiency of the reaction principle used for the ascent, as is frequently and incorrectly thought to be the case. Naturally, energy is lost during the ascent, as has been previously determined[12], due to the condition that the travel velocity during the application of the propulsion increases only gradually and, therefore, is not of an equal magnitude (namely, in the beginning smaller, later larger) with the exhaust (repulsion) velocity (Figure 17). Nevertheless, the average efficiency of the reaction[13] would be 27 percent at a constant exhaust velocity of 3,000 meters per second and 45 percent at a constant exhaust velocity of 4,000 meters per second, when, for example, the vehicle is supposed to be /63

---

[11] See Pages 49 through 52.

[12] See Pages 35 through 40.

[13] Using the formula on Page 37 and 38.

accelerated to the velocity of 12,500 meters per second, ideally necessary for complete separation from the Earth. According to our previous considerations, the efficiency would even attain a value of 65 percent in the best case; i.e., for a propulsion phase in which the final velocity imparted to the vehicle is 1.59 times the exhaust velocity[14].

Since the internal efficiency of the propulsion equipment can be estimated at approximately 60 percent on the basis of the previously discussed Goddard experiments and on the experiences of ballistics[15], it follows that an average total efficiency of the vehicle of approximately 16 to 27 percent (even to 39 percent in the best case) may be expected during the ascent, a value which, in any case, is no worse than for our present day automobiles! Only the enormous power necessary for overcoming such vast altitudes requires such huge amounts of fuel. /64

If, by way of example, a street would lead from the Earth into outer space up to the practical gravitational boundary, and an automobile is supposed to drive up that street, then an approximately equally large supply of fuel including the oxygen necessary for combustion would have to be stored on the automobile, as would be necessary for equivalent fuels for a space ship with the same load and altitude.

It is still of interest to know how Oberth evaluated the question of costs. According to his data, the previously described smaller model including the preliminary experiments would cost 10,000 to 20,000 marks. The construction costs of a space ship, compatible for transporting one observer, would be over 1 million marks.

---

[14] See Table 4 on Page 39.

[15] See Page 57.

Under good conditions, the space ship would be capable of carrying out approximately 100 flights. In the case of a larger space ship, which transports, besides the pilot together with the equipment, 2 tons of freight, an ascent to the stable state of suspension (transition into a free orbit) would require approximately 50,000 to 60,000 marks.

*

The study published by Dr. of Engineering Hohmann about the problem of space flight does not address the construction of space rockets in more detail, but rather thoroughly addresses all fundamental questions of space flight and provides very valuable recommendations /65 related to this subject. As far as questions relating to the landing process and distant travel through outer space are concerned, they will be addressed later.

What is interesting at this point is designing a space vehicle for transporting two people including all necessary equipment and supplies. Hohmann conceives a vehicle structured in broad outlines as follows: the actual vehicle should consist only of the passenger cell. In the latter, everything is stored – with the exception of the fuel. A solid, explosive-like substance serving as the fuel would be arranged below the passenger cell in the shape of a spire tapering upward in such a way that the passenger cell forms its peak (Figure 34). As a result of a gradual burning of this fuel spire, thrust will be generated similar to a fireworks rocket. A prerequisite for this is that explosive experts find a substance which, on the one hand, has sufficient strength to keep itself in the desired shape and which, on the other hand, also has that energy of combustion necessary for generating a correspondingly large velocity of repulsion.

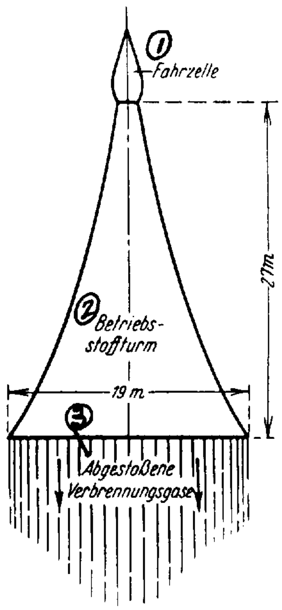


Figure 34. The space rocket according to Hohmann.

Key: 1. Passenger cell; 2. Fuel tower; 3. Escaping gases of combustion

Assuming that this velocity would be 2,000 meters per second, a space vehicle of this nature would weigh, according to Hohmann, 2800 tons all told in the launch-ready state, if it is supposed to be capable of attaining an altitude of 800,000 km (i.e., twice the distance to the moon). This corresponds approximately to the weight of a small ocean liner. A round trip of this nature would last 30.5 days.

Recent publications by Dr. von Hoefft are especially noteworthy. /66

His original thought was to activate the propulsion system of space ships using universal ether. For this purpose, a one-sided ether flow is supposed to be conducted through the vehicle by means of an electrical effect. In accordance with Hoefft's assumption, the reaction effect of the ether occurring as a result would then supply the propulsion force of the vehicle, something which assumes that ether has mass. Hoefft, however, maintained that that was a given if the opinion held by Nernst and other researchers actually applies, according to which a very significant internal energy should be inherent in universal ether (zero point energy of the ether); more specifically, this is substantiated by the fact that energy is also associated with mass in accordance with Einstein's Law.

Taking the improbability into account of being able to implement these concepts in the foreseeable future, von Hoefft has now agreed with Oberth's efforts. According to reports, his latest research on this subject has resulted in developing designs which are only awaiting funding.

He intends initially to put an unmanned recording rocket at an altitude of approximately 100 km for the purpose of exploring the upper layers of air. This rocket is not segregated, is powered by alcohol and liquid oxygen and is controlled by means of a gyroscope like the kinds used in torpedoes. The height of the rocket is 1.2 meters, its diameter is 20 cm, its initial (launch) weight is 30 kg and its final weight is 8 kg, of which 7 kg are allocated to empty weight and 1 kg to the payload. The latter is composed of a meteorograph stored in the top of the rocket and separated automatically from the rocket as soon as the altitude is attained, similar to what happens in recording balloons. The meteorograph then falls alone slowly to Earth on a self-opening parachute, recording the pressure, temperature and humidity of the air. The ascent is supposed to take place from an altitude of 10,000 meters from an unmanned rubber balloon (pilot balloon) to save the rocket from having to penetrate the lower, dense layers of air.

As the next step, von Hoefft plans to build a larger /67
rocket with an initial weight of 3,000 kg and a final weight of 450 kg, of which approximately 370 kg are allocated to empty weight and 80 kg to the payload. Similar to how a projectile is used, the rocket is supposed to cover vast

distances of the Earth's surface (starting at approximately 1,500 km) in the shortest time in a free trajectory (Keplerian ellipses) and either transport mail or similar articles or photograph the regions flown over (for examples, the unexplored ones) with self-acting camera equipment.

Landing is envisaged in such a manner that the payload is separated automatically from the top before the descent, similar to the previously described recording rocket, descending by itself on a parachute.

This single-stage rocket is also supposed to be configured into a two-stage one and as a result be made compatible for a moon shoot. For this purpose, it is equipped, in place of the previous payload of approximately 80 kg, with a second rocket equally as heavy; this rocket will now carry the actual, admittedly considerably smaller payload of approximately 5 to 10 kg. Because the final velocities of both subrockets in a dual rocket of this type are additive during the power ascent in accordance with the previously explained staging principle[16], a highest climbing velocity of this magnitude would be attained which is sufficiently large to bring the payload consisting of a load of flash powder to the moon. When landing on the moon, this load is supposed to ignite, thus demonstrating the success of the experiment by lighting up, which is similar to that intended by Goddard.

Both this and the aforementioned mail rocket are launched from an altitude of 6,000 meters from a pilot balloon, thrust rocket or mountain top.

In contrast to these previously described unmanned /68
rockets, the large space vehicles designed for transporting people, which Hoefft then plans to build in a follow-on effort, are basically supposed to be launched only directly from a suitable area over water, more specifically like a

[16] See Pages 52 through 55.

seaplane, and during the descent land on water, similar to a plane of that type. The rockets are supposed to be given an entirely special external shape (somewhat similar to a kite) in order to make them capable for this trip.

As initially planned, the model of a space vehicle of this type would have a launch weight of 30 tons and a final weight of 3 tons. Its purpose is the following: on the one hand, to be employed similar to the mail rocket yet occupied by people who are to be transported and to cover great distances of the Earth's surface in a free trajectory (Keplerian ellipses) in the shortest time; and, on the other hand, it would later have to serve as an upper stage of larger, multi-staged space ships designed for reaching alien celestial bodies. Their launch weights would then be fairly significant: several 100 tons and even up to 12,000 tons for the larger designs.

## Comments Regarding Previous Design Recommendations

Regarding these various recommendations, the following is added as supplementary information: as far as can be seen from today's prospective, the near future belongs in all probability to the space rocket with a liquid fuel. Fully developed designs of such rockets will be achieved when the necessary technical conditions have been created through a practical solution (obtained in experimental methods) of the questions fundamental to their design: 1. the method of carrying the fuels on board, 2. the method of injecting fuel into the oven and 3. the precautions against destroying the oven and nozzle resulting from the heat of combustion.

For this reason, we intentionally avoided outlining our own design recommendations here. Without a doubt, we consider it advisable and necessary, even topical, at least /69 as far as it is possible using currently available experiences, to clarify the fundamentals of the vehicle's structure, and the question of propellant belongs mainly to this subject. According to what has been stated beforehand, hydrogen and oxygen, on the one hand, and alcohol and oxygen, on the other, were previously suggested as propellants.

In the opinion of the author, the pure hydrocarbon compounds (together with the oxygen necessary for combustion) should be better suited than the ones referenced in the previous paragraph as fuels for space rockets. This becomes understandable when the energy content is expressed as related to the volume instead of to the weight, the author maintaining this being the most advantageous method in order to be able to evaluate the valence of a rocket fuel in a simple fashion. Then, it is not only a matter of what amount of fuel by weight is necessary for a specific performance, but still more important for storing the fuel, and as a result for designing the vehicle, is what amount of fuel by volume must be carried on board. In the latter regard, the energy content (thermal units per liter) of the fuel related to the volume provides the clearest information.

This energy content is that much more significant the greater the specific weight as well as the net calorific value of the fuel under consideration are and the less oxygen it requires for its combustion. In general, the carbon-rich compounds are shown to be superior to the hydrogen-rich ones, even though the calorific value per kilogram of the latter is higher. Consequently, benzene would appear very suitable, for example. Pure carbon would be the best. Because the latter, however, is not found in the fluid state, attempts should be made to ascertain whether by mechanical mixing of a liquid hydrocarbon (perhaps benzene, haptene, among others) with an energy content per liter as high as possible with finely-dispersed carbon as pure as possible (for instance carbon black, the finest coal dust or similar products), the energy content per liter could be increased still further and as a result particularly high quality rocket fuel could be obtained which is perhaps the best possible overall in accordance with our current knowledge of substances.

An obvious condition for the validity of the present considerations is naturally that all fuels are utilized with the same efficiency. /70

Under this assumption by way of example, a space rocket, which is supposed to attain the final velocity of 4,000 meters per second and when it is powered with benzene and liquid oxygen, would turn out to be smaller by about one-half and have a tank surface area smaller by one-third than when powered by liquid hydrogen and oxygen (Figure 35).

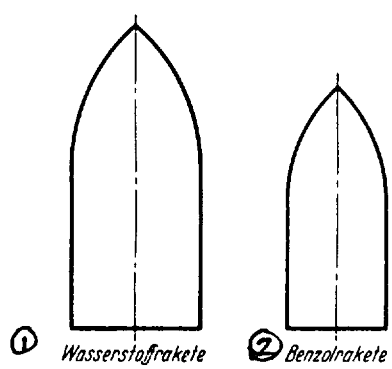


Figure 35. Size relationship between a hydrogen rocket and a benzene rocket of the same performance, when each one is supposed to be capable of imparting a velocity of 4,000 meters per second.

Key: 1. Hydrogen rocket; 2. Benzene rocket.

Therefore, the benzene rocket would not only be realized sooner from an engineering point of view, but also constructed more cheaply than the hydrogen rocket of the same efficiency. Even though the weight of the necessary amount of fuel is somewhat higher in the former case and, therefore, a larger propulsion force and, consequently, stronger, heavier propulsion equipment would be required. Instead, the fuel tanks are smaller for benzene rockets and, furthermore, as far as they serve the purposes of benzene at least, can be manufactured from any light-weight metal because benzene is normally liquid. When considering its abnormally low temperature (-235° Celsius) per Oberth, a point made previously, rockets for liquefied hydrogen would have to be made of lead (!). This discussion ignores completely the many other difficulties caused by this low temperature in handling liquid hydrogen and the method of using this fuel; all of these difficulties disappear when using benzene.

/71

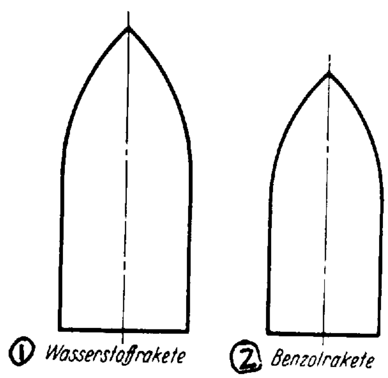


Figure 36. Size relationship between a hydrogen rocket and a benzene rocket of the same performance, when each one is supposed to be capable of imparting a velocity of 12,500 meters per second (complete separation from the Earth!).

Key: 1. Hydrogen rocket; 2. Benzene rocket

However, this superiority of liquid hydrocarbons compared to pure hydrogen diminishes more and more at higher final velocities. Nevertheless, a benzene rocket would, however, still turn out to be smaller by one-third than a hydrogen rocket, even for attaining a velocity of 12,500 meters per second (as is ideally necessary for complete separation from the Earth) (Figure 36). Only for the final velocity of 22,000 meters per second, the volumes of fuels for the benzene rocket would be equally as large as for the hydrogen rockets.

Besides these energy-efficient advantages and other ones, liquid hydrocarbons are also considerably cheaper than pure fluid hydrogen.

## The Return to Earth

The previous explanations indicate that obstacles stand in the way of the ascent into outer space which although significant are nonetheless not insurmountable. Based solely on this conclusion and before we address any further considerations, the following question is of interest: Whether and how it would be possible to return to Earth after a successful ascent and to land there without experiencing any injuries. Then, it would arouse a terrible horror even in the most daring astronaut when he thinks, seeing the Earth as a distant sphere ahead of him, that he will land on it with a velocity having no less than approximately 12 times the velocity of an artillery projectile as soon as he, freely yielding himself to its /72
gravity, travels towards it or more correctly stated, crashes onto it.

The rocket designer must provide for timely braking. What difficult problem is intrinsic in this requirement is realized when we visualize that a kinetic force, which almost equals that of an entire express train moving at a velocity of 70 km/hour, is inherent in each single kilogram of the space ship during its landing on Earth! Then, as described in the beginning, an object always falls onto the Earth with the velocity of approximately 11,000 meters per second as soon as it is pulled from outer space towards the Earth by the Earth's gravitational force. The object has then a kinetic force of around 6,000 metric tons per kilogram of its weight. This enormous amount of energy must be removed in its entirety from the vehicle during braking.

Only two possibilities are considered in this regard: either counteracting the energy by means of reaction propulsion (similar to the "reverse energy" of the machine when stopping a ship, by way of example) or rheostatic braking by using the Earth's atmosphere.

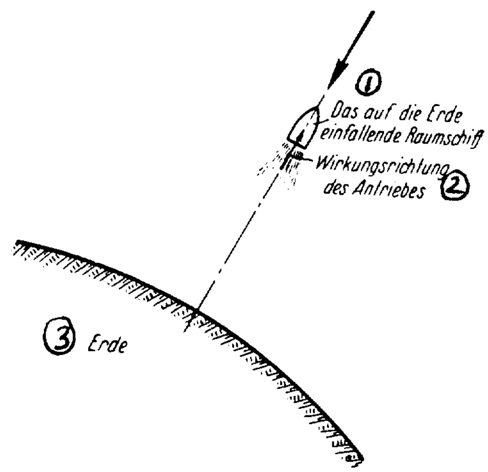


Figure 37. Landing with reaction braking. The descending vehicle is supposed to be "cushioned" by the propulsion system, with the latter functioning "away from the Earth" opposite to the direction of flight, exactly similar to the ascent.

Key: 1. The space ship descending to the Earth; 2. Direction of effect of the propulsion system; 3. Earth

When landing according to the first method, the propulsion system would have to be used anew, and more specifically, counter to the direction of flight (Figure 37). In this regard, the vehicle's descent energy would be removed from it by virtue of the fact that the same amount of energy is offset by the performance of an equally large, opposite energy. This requires, however, that the same energy for braking and, therefore, the same amount of fuel necessary for the ascent would have to be consumed. Then, since the initial velocity for the ascent (highest climbing velocity) and the final velocity during the return (descent velocity) are of similar magnitudes, the kinetic forces, which must be imparted to the vehicle in the former case and removed in the latter case, differ only slightly from one another.

For the time being, this entire amount of fuel necessary for braking must, however, still – and this is critical – be lifted to the final altitude, something which means an enormous increase of the climbing load. As a result, however, the amount of fuel required in total for the ascent becomes now so large that this type of braking appears in any case extremely inefficient, even non-implementable in the first place for the performance level of currently available fuels. However, even only a partial usage of the reaction for braking must be avoided if at all possible for the same reasons. /73

Presumably, the point that reaction braking in the region of the atmosphere may hardly be useable in the first place – at least as long as the travel velocity is still of a cosmic magnitude – must additionally be considered. Then, the exhaust gases, which the vehicle drives ahead of it, would be decelerated more by air drag than the heavier vehicle itself and, therefore, the vehicle would have to travel in the heat of its own gases of combustion.

The second type of landing, the one utilizing air drag, is brought about by the fact that the vehicle is braked during its travel through the Earth's atmosphere by means of a parachute or other means (Figure 38). It is critical in this regard that the kinetic force, which must be removed from the vehicle during this process, is only converted partially into air movement (eddying) and partially into heat. If now the braking distance is not sufficiently long and consequently the braking period is too short, then the resulting braking heat cannot transition to the environment through conduction and radiation to a sufficient degree,

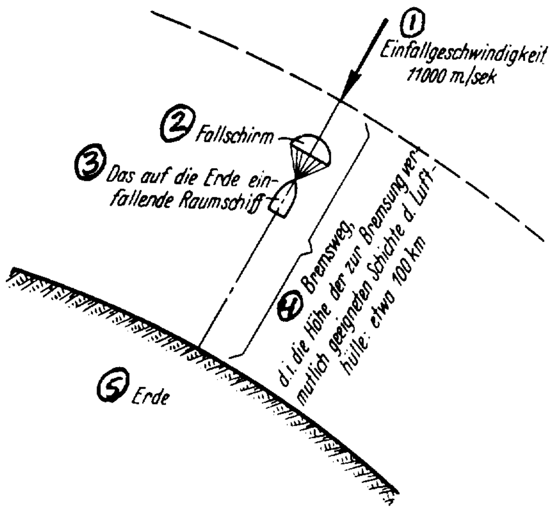


Figure 38. Landing during a vertical descent of the vehicle using air drag braking.

Key: 1. Descent velocity of 11,000 m/sec; 2. Parachute; 3. The space ship descending to Earth; 4. Braking distance, i.e., the altitude of the layers of the atmosphere (approx. 100 km) probably suitable for braking; 5. Earth.

causing the temperature of the braking means (parachute, etc.) to increase continuously.

Now in our case, the vehicle at its entry into the atmosphere has a velocity of around 11,000 meter per second, while that part of the atmosphere having sufficient density for possible braking purposes can hardly be more than 100 km in altitude. According to what was stated earlier, it is fairly clear that an attempt to brake the vehicle by air drag at such high velocities would simply lead to combustion in a relatively very short distance.

It would appear, therefore, as if the problem of space /75 flight would come to nought if not on the question of the ascent then for sure on the impossibility of a successful return to Earth.

## Hohmann's Landing Maneuver

German engineer Dr. Hohmann performed a service by indicating a way out of this dilemma. According to his recommendation, the vehicle will be equipped with wings for landing, similar to an airplane. Furthermore, a tangential (horizontal) velocity of such a nature is imparted to the vehicle at the start of the return by means of reaction that the vehicle does not even impact on its surface during its descent to Earth, but travels around the Earth in a free orbit in such a manner that it approaches within 75 km of the Earth's surface at the top of the orbit (Figure 39).

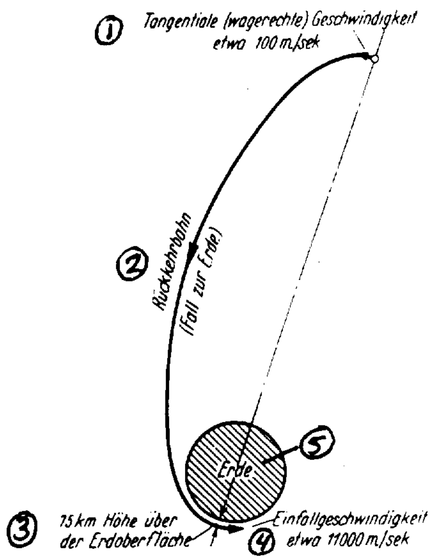


Figure 39. During Hohmann's landing process, the return orbit is artificially influenced to such an extent that the space ship does not even impact the Earth, but travels around it at an altitude of 75 km.

Key: 1. Tangential (horizontal) velocity of approx. 100 m/sec; 2. Return orbit (descent to Earth); 3. At an altitude 75 km above the Earth's surface; 4. Descent velocity of approximately 11,000 m/sec; 5. Earth

I will try to explain this process in a simple fashion as follows: if a stone is thrown instead of allowing it to simply drop, then it hits the ground a certain distance away, and more specifically, at a greater distance, the greater the velocity at which it was thrown. If this throw velocity could now be arbitrarily increased such that the stone falls not a distance of 10 or 100 meters, not even at distances of 100 or 1,000 km, but only reaches the Earth at a distance of 40,000 km away, then in reality the stone /76 would no longer descend at all because the entire circumference of the Earth measures only 40,000 km. It would then circle the Earth in a free obit like a tiny moon. However, in order to achieve this from the stand point of the Earth's surface, the very high velocity of approximately 8,000 meters per second would have to be imparted to the stone. This velocity, however, becomes that much smaller the further the position, from which the object is supposed to be put into orbit around the Earth, is distant from it. At a distance of several hundred thousand km, the velocity is only around 100 meters per second (Figure 39). This can be understood if we visualize that at any rate the vehicle gains velocity more and more – solely due to its descent to Earth. According to what was stated previously, if the descent velocity finally attains the value of 11,000 meters per second, it is then greater by more than 3,000 meters per second than that velocity of exactly 7,850 meters per second which the vehicle would have to have so that it would travel around the Earth (similar to the stone) in a free circular orbit at an altitude of 75 km.

Due to the velocity excess, the space ship is now more forcefully pushed outward by the centrifugal force than the force of gravity is capable of pulling it inward towards the Earth. This is a process similar, for instance, to that of an automobile driving (too "sharply") through a curve at too high a speed (Figure 40). Exactly as this automobile is accelerated outward because the centrifugal force trying to force it off the road is greater than the friction of the

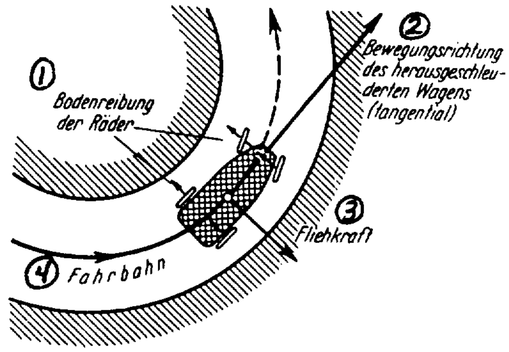


Figure 40. If the centrifugal force becomes extremely large due to excessively rapid travel, it hurls the automobile off the road.

Key: 1. Friction of the wheels on the ground; 2. Direction of motion of the automobile being accelerated (tangential); 3. Centrifugal force; 4. Road.

wheels trying to keep it on the road, our space ship will – in a symbolic sense – also strive to exit the free circular orbit in an outward direction and, as a result, to move again away from the Earth (Figure 41).

## Landing in a Forced Circular Motion

The situation described above can, however, be prevented, more specifically, with the appropriate help of wings. In the case of a standard airplane, the wings are pitched upward so that, as a result of the motion of flight, that lift occurs which is supposed to carry the airplane (Figure 42). In our case, the wings are now adjusted in the opposite direction, that is, pitched downward (Figure 43). As a result, a pressure directed downward towards the Earth occurs, exactly offsetting the centrifugal force excess by properly selecting the angle of incidence and in this fashion forcing the vehicle to remain in the circular flight path (Figure 44).

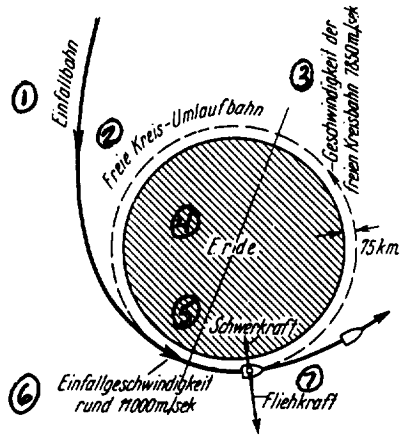


Figure 41. Due to the travel velocity (11,000 instead of 7,850 m/sec!) which is excessive by around 3,000 m/sec, the centrifugal force is greater than the force of gravity, consequently forcing the space ship outward out of the free circular orbit.

Key: 1. Descent orbit; 2. Free circular orbit; 3. Velocity in the free circular orbit of 7,850 m/sec; 4. Earth; 5. Force of gravity; 6. Descent velocity of around 11,000 m/sec; 7. Centrifugal force.

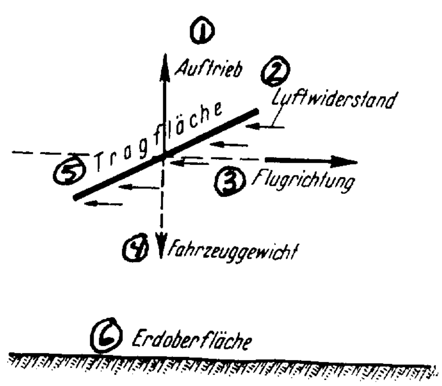


Figure 42. The fundamental operating characteristics of wings during standard heavier-than-air flight: The "lift" caused by air drag is directed upward and, therefore, carries the airplane.

Key: 1. Lift; 2. Air drag; 3. Direction of flight; 4. Weight of the vehicle; 5. Wings; 6. Surface of the Earth.

For performing this maneuver, the altitude was intentionally selected 75 km above the Earth's surface, because at that altitude the density of air is so thin that the space ship despite its high velocity experiences almost the same air drag as a normal airplane in its customary altitude. /78

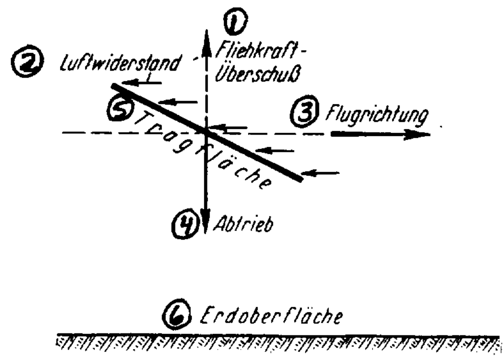


Figure 43. The operating characteristics of wings during the "forced circular motion" of a landing space ship. Here, air drag produces a "negative lift" directed towards the Earth (downward), offsetting the centrifugal force excess.

Key: 1. Centrifugal force excess; 2. Air drag; 3. Direction of flight; 4. Negative lift; 5. Wings; 6. Surface of the Earth.

During this "forced circular motion," the travel velocity is continually being decreased due to air drag and, therefore, the centrifugal force excess is being removed more and more. Accordingly, the necessity of assistance from the wings is also lessened until they finally become completely unnecessary as soon as the travel velocity drops to 7,850 meters per second and, therefore, even the centrifugal force excess has ceased to exist. The space ship then circles suspended in a circular orbit around the Earth ("free circular motion," Figure 44).

Since the travel velocity continues to decrease as a result of air drag, the centrifugal force also decreases gradually and accordingly the force of gravity asserts itself more and more. Therefore, the wings must soon become active again and, in particular, acting exactly like the typical airplane (Figure 42): opposing the force of gravity, that is, carrying ("glided motion," Figure 44).

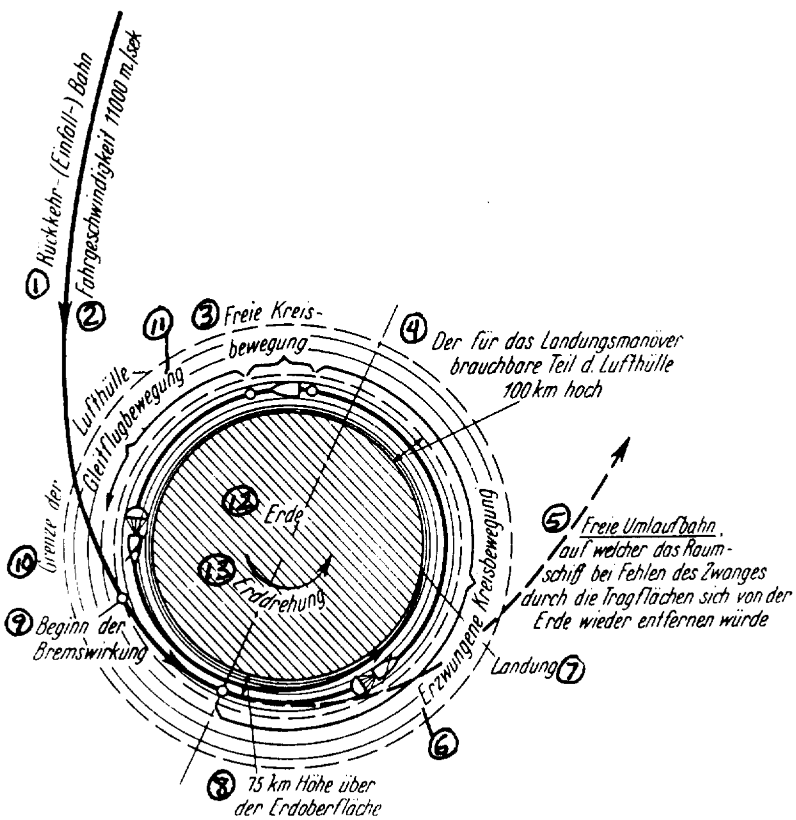


Figure 44. Landing in a "forced circular motion." (The atmosphere and the landing spiral are drawn in the figure – for the purpose of a better overview – higher compared to the Earth than in actuality. If it was true to scale, it would have to appear according to the ratios of Figure 8.)

Key: 1. Return (descent) orbit; 2. Travel velocity of 11,000 m/sec; 3. Free circular motion; 4. The part of the atmosphere 100 km high useable for landing; 5. Free Orbit, in which the space ship would again move away from the Earth when the wings fail to function; 6. Forced circular motion; 7. Landing; 8. An altitude of 75 km above the Earth's surface; 9. Start of braking; 10. Boundary of the atmosphere; 11. Glided motion; 12. Earth; 13. Rotation of the Earth.

Finally, the centrifugal force for all practical purposes becomes zero with further decreasing velocity and with an increasing approach to the Earth: from now on, the vehicle is only carried by the wings until it finally descends in glided flight.

In this manner, it would be possible to extend the /79 distance through the atmosphere to such an extent that even the entire Earth would be orbited several times. During orbiting, however, the velocity of the vehicle could definitely be braked from 11,000 meters per second down to zero partially through the effect of the vehicle's own air drag and its wings and by using trailing parachutes, without having to worry about "overheating." The duration of this landing maneuver would extend over several hours.

## Landing in Braking Ellipses /80

In the method just described, transitioning from the descent orbit into the free circular orbit and the required velocity reduction from 11,000 to 7,850 meters per second were performed during the course of the "forced circular motion." According to another Hohmann recommendation, this can also be achieved by performing so-called "braking ellipses" (Figure 45). In this landing procedure, the wings are not used initially, but braking is performed as vigorously as the previously explained danger of excessive heating will permit by means of a trailing parachute as soon as the vehicle enters into sufficiently dense layers of air.

However, the travel velocity, as a result, cannot be /81 decreased to such an extent as would be necessary in order to transition the space ship into free circular motion. An excess of velocity, therefore, still remains and consequently of centrifugal force which now pushes the vehicle outward such that it again departs the atmosphere and will move away from the Earth in a free orbit of an



C-2

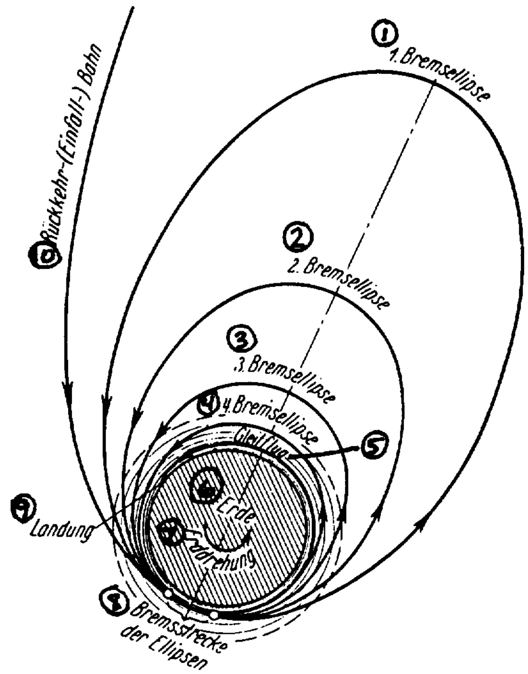


Figure 45. Landing in "braking ellipses." (The atmosphere and landing orbit are drawn here higher than in reality, exactly similar to Figure 44. Reference Figure 8.)

Key: 1. First braking ellipse; 2. Second braking ellipse; 3. Third braking ellipse; 4. Fourth braking ellipse; 5. Glided flight; 6. Earth; 7. Rotation of the Earth; 8. Braking distance of the ellipses; 9. Landing; 10. Return (descent) orbit.

elliptical form (first braking ellipse). The vehicle, however, will not move away to that distance from which it originally started the return flight, because the kinetic force has already decreased during the braking (Figure 45). Due to the effect of gravity, the vehicle will re-return to Earth after some time later, again travel through the atmosphere — with a part of its velocity again being nullified by parachute braking —, moving away from the Earth once again, this time, however, in a smaller elliptical orbit (second braking ellipse), then returning again, and so on.

Therefore, narrower and narrower so-called "braking ellipses" will be flown through one after the other corresponding to the progressive velocity decrease, until finally the velocity drops to 7,850 meters per second and as a result the free circular motion is initiated. The further course of the landing then occurs with the help of wings in glided flight, just as in the previously described method. The entire duration of the landing from the initial entry into the atmosphere to the arrival on the Earth's surface is now around 23 hours; that is, it is longer by a multiple than in the case of the method previously described. Therefore, the wings intended in any case for the Hohmann landing will be utilized to their full extent even at the start and consequently the landing will be performed better in a forced circular motion.

## Oberth's Landing Maneuver

The case is different, however, when wings are not to be used in the first place, as recommended by Oberth, who also addresses the landing problem in more detail in the /82 second edition of his book. As described, the first part of the landing is carried out similarly to the one previously described using braking ellipses (Figure 45), with wings not being required in this part of the landing. The subsequent landing process can, however, not take place in glided flight because the wings are missing. The parachute is supposed to be positioned inclined to the direction of flight by shortening one side of the parachute lines and as a result attain a lift (that is, an effect similar to wings). Nevertheless, using propulsion to a very extensive degree could prove necessary in order to prevent an excessively rapid descent of the vehicle, such that doing without the wings could only be had at the expense of a fairly significant load of fuel. This assumes that applying reaction braking within the atmosphere would be possible in the first place based on previously stated reasons (a threat due to the vehicle's own gases of combustion).

All things considered, the landing according to Hohmann in a "forced circular motion" by means of wings appears, therefore, to represent the most relevant solution.

## The Result To Date

We have seen that not only the ascent into outer space, but also the assurance of a controlled return to Earth is within the range of technical possibility, such that it does not appear justified whatsoever to dismiss out of hand the problem of space flight as utopia, as mankind would be inclined to do in a traditional sense when evaluating only superficially. No fundamental obstacles whatsoever exist for space ship flight and even the current scientific and engineering prerequisites justifiably anticipate the eventual implementation of this boldest of all human dreams. Of course, years and decades can pass until this happens, because the technical difficulties yet to be overcome are very significant and no serious thinking person should fool himself on this point. In many respects, it will probably be shown as necessary in the practical implementation to /83
alter extensively the recommendations which were proposed to date without a sufficient experimental basis. It will cost money and effort and perhaps even human life. We have after all experienced all of these costs and efforts when conquering the skies! Nevertheless as far as technology is concerned, once we have recognized something as correct and possible, then the implementation inevitably follows, even when extensive obstacles had to eliminated – assuming, however, that the matter at hand appears to have a good pay off.

## Two Other Important Questions

Therefore, we now want to attempt to show which prospects the result indicated above opens up for the future and to clarify two other existing important questions, because up to this point we have addressed only the technical side of the problem, not its economical and physiological sides, however.

What are the practical and other advantages, which we could expect from implementing space travel, and would they be sufficiently meaningful to allow all the necessary, yet powerful applications appear, in fact, to have a pay off?

And, on the other hand, could human life be made possible in the first place under the completely altered physical conditions existing in empty space, and what special precautions would be necessary in this regard?

The answer to these questions will become obvious by examining in more detail in the following the prospective application options of space ship travel.

Usually in considerations of this nature, mankind thinks primarily of traveling to alien celestial bodies and walking on them, as has been described in a romantic way by individual authors. However, regardless of how attractive this may appear, it would, in any case, only form the final /84
phase of a successful development of space ship travel. Initially, however, there would be many applications for space travel which would be easier to implement because they would not require completely departing the Earth's orbit, our home star, and moving in alien, unknown worlds.

## The Space Rocket in an Inclined Trajectory

For the rocket, the simplest type of a practical application as a means of transportation results when it climbs in an inclined (instead of vertical) direction from the Earth, because it describes a parabolic trajectory (Figure 46). It is well known in this regard that the range is the maximum when the ballistic angle (angle of departure) – in our case, the angle of inclination of the direction of ascent – is 45° (Figure 47).

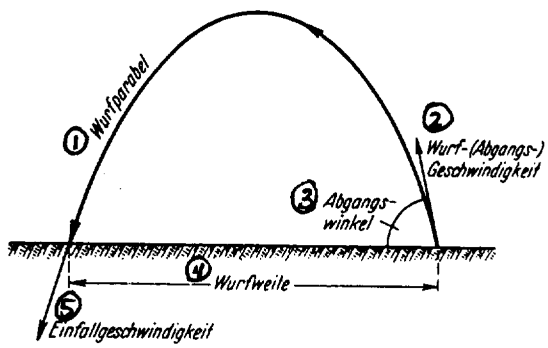


Figure 46. Inclined trajectory.

Key: 1. Parabolic trajectory; 2. Ballistic (departure) velocity; 3. Angle of departure; 4. Range; 5. Descent velocity.

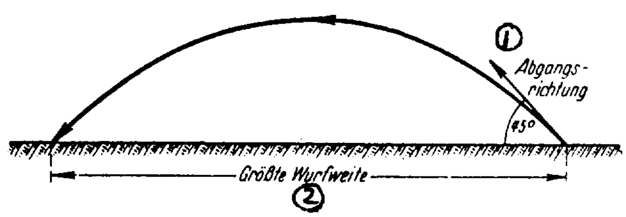


Figure 47. The greatest distance is attained for a given departure velocity when the angle of departure is 45°.

Key: 1. Direction of departure; 2. Greatest distance.

In this type of application, the rocket operates similarly to a projectile, with the following differences, however: a cannon is not necessary to release it; its weight can be larger by a factor than is the case with the typical, yet very powerful projectile; the departure acceleration can be selected as arbitrarily small; nevertheless, such high departure velocities could be attained that there would theoretically be no terrestrial limit whatsoever for the ballistic (firing) range of the space rocket.

Accordingly in an extremely short period, a load could be carried over very great distances, resulting in the opinion that this method could be used for transporting, for example, urgent freight, perhaps under the control of the post office, telecommunication office or similar service organizations. /85

The latter method would, however, only be possible when the descent velocity of the incoming rocket is successfully slowed in time to such a degree that the vehicle impacts softly because otherwise it and/or its freight would be destroyed. According to our previous considerations[17], two braking methods are available in this regard as follows: either by means of reaction or by air drag. Because the former must necessarily be avoided, if at all possible, due to the enormous related fuel consumption, then only the application of air drag is possible.

Braking would obviously not be achieved with a simple parachute landing, because, considering the extent of possible ranges, the rocket descends to its destination with many times the velocity of a projectile. For this situation, however, the braking distance, which would result in the atmosphere in the best case, would be much too short due to the excessive steepness of the descent. Additionally, the disadvantage exists that the main part of the descent velocity would take place in the lower, dense layers of air during braking.

This is equally valid even when, as suggested by another party, the entire procedure is controlled to such a degree that the payload is separated from the rocket before the descent so that it can descend by itself on a parachute,

---

[17] See Page 77.

while the empty shell of the rocket is abandoned. Then, neither the magnitude of the descent velocity nor the primarily dangerous steepness of the descent is somehow influenced favorably by this procedure.

In order to deliver the freight undamaged to the /86 destination, braking, if it is supposed to be caused by air drag, could only happen during a sufficiently long lasting, almost horizontal flight in the higher, thin layers of air selected corresponding to the travel velocity – that is, according to Hohmann's landing method (glided landing). And, braking would consequently be extended over braking distances which would not be that much shorter than the entire path to be traveled.

Therefore, proper ballistic motion would not be realized whatsoever – for the case that braking should occur before the impact –, but rather a type of movement would result as will be discussed in the next section entitled "The Space Rocket as an Airplane."

In a pure inclined trajectory, the rocket would only be used when a "safe landing" is not required, for example, like a projectile used in warfare. In the latter case, solid fuels, such as smokeless powder and similar substances, could easily be used for propelling the rockets in the sense of Goddard's suggestion, as has been previously pointed out[18].

To provide the necessary accuracy to rocket projectiles of this type is in any case only a question of improving them from a technical standpoint. By the way, the large targets coming mainly under consideration (such as large enemy cities, industrial areas, etc.) tolerate relatively significant dispersions in any case.

---

[18] See Pages 45 and 56.

If we now consider that when firing rockets in this manner even heavy loads of several tons could safely be carried over vast distances to destinations very far into the enemy's heartland, then we understand what a terrible weapon we would be dealing with. It should also be noted that after all almost no area of the hinterland would be safe from attacks of this nature and there would be no defense against them at all. /87

Nevertheless, its operational characteristics are probably not as entirely unlimited as would actually be expected when taking the performance of the rocket propulsion system into consideration, because with a lengthening of the range the velocity also increases at which the accelerated object, in this case the rocket, descends to the target, penetrating the most dense layers of

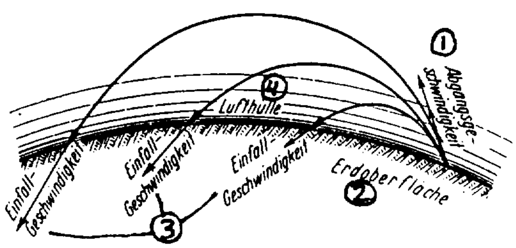


Figure 48. The greater the range, the greater the descent velocity will be (corresponding to the greater departure velocity and altitude necessary for this).

Key: 1. Departure velocity; 2. Earth's surface; 3. Descent velocity; 4. Atmosphere.

air near the Earth's surface (Figure 48). If now the range and the related descent velocity are too large, then the rocket will be heated due to air drag to such an extent that it is destroyed (melted, detonated) before it reaches the target at all. This is similar to meteorites falling onto the Earth which only rarely reach the ground because they burn up in the atmosphere due to their considerably greater descent velocity, admittedly at a much more extensive elevation. In this respect, the Earth's atmosphere would probably provide us at least partial protection in this regard, as is the case in several other respects.

No doubt, the simplest application of the rocket just /88
described probably doesn't exactly appear to many as an endorsement for it! Nevertheless, it is the fate of almost all significant accomplishments of technology that they can also be used for destructive purposes. Should, for example, chemistry be viewed as dangerous and its other forms as undesirable because it creates the weapons for insidious gas warfare? And the results, which we would come to expect from a successful development of space rockets, would surpass by far everything which technology was capable of offering to date, as we will recognize in the following discussion.

## The Space Rocket as an Airplane

As previously described, Hohmann recommends equipping the space ship with wings for landing. At a certain stage of his landing manoeuver[19], the space ship travels suspended around the Earth in a circular, free orbit ("carried" only by centrifugal force) at an altitude of 75 km and at a corresponding velocity of 7,850 meters per second ("free circular motion," Figure 44). However, because the travel velocity and also the related centrifugal force continually decrease in subsequent orbits, the vehicle becomes heavier and heavier, something the wings now must assimilate so that the free orbital motion transitions gradually into a glided flight. Accordingly, deeper and deeper, denser layers of air must be flown through so that

---

[19] See Page 84.

their drag corresponds the best for achieving the necessary lift at the diminished travel velocity and for the increased load ("glided motion," Figure 44).

Since even the entire Earth will now be orbited in only a few hours in this process, it becomes obvious to establish in a similar fashion terrestrial express flight transportation at the highest possible, almost cosmic velocities:

If an appropriately built space ship equipped with wings climbs only up to an altitude of approximately 75 km and at the same time a highest horizontal velocity of 7,850 meters per second is imparted to it in the direction of a /89

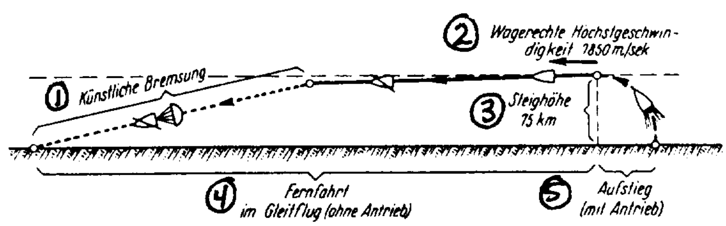


Figure 49. Schematic representation of an "express flight at a cosmic velocity" during which the highest horizontal velocity is so large (in this case, assumed equal to the velocity of free orbital motion) that the entire long-distance trip can be covered in glided flight and must still be artificially braked before the landing.

Key: 1. Artificial braking; 2. Highest horizontal velocity of 7,850 m/sec; 3. Altitude of 75 km; 4. Long-distance trip in glided flight (without power); 5. Ascent (with power).

terrestrial destination (Figure 49), then it could cover the distance to that destination without any further expenditure of energy: in the beginning in an approximately circular free orbit, later more and more in glided flight and finally in it totally, only carried by atmospheric lift. In time before the landing, the velocity would finally have to be appropriately decreased through artificial air drag braking, for example, by means of a trailing parachute.

Even though this type of landing faces several difficulties at high velocities of this magnitude it, on the other hand, could easily be successful when the highest horizontal velocity is selected smaller because less artificial braking would be necessary as a result. At a certain highest horizontal velocity, even natural braking would suffice for this purpose as a result of an unavoidable travel resistance (Figure 50).

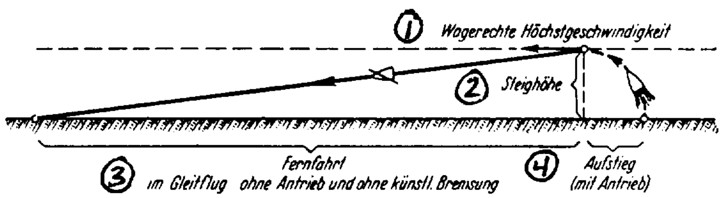


Figure 50. Schematic representation of an "express flight at a cosmic velocity" during which the highest horizontal velocity is just sufficient to be able to cover the entire long-distance trip in glided flight when any artificial braking is avoided during the flight.

Key: 1. Highest horizontal velocity; 2. Altitude; 3. Long-distance travel in glided flight without power and without artificial braking; 4. Ascent (with power)

In all of these cases, the vehicle requires no power whatsoever during the long-distance trip. If the vehicle is then powered only by a booster rocket – that is, "firing" more or less with the booster – during the ascent (until it reaches the required flight altitude and/or the highest horizontal velocity), then the vehicle could cover the longer path to the destination solely by virtue of its "momentum" (the kinetic force received) and does, therefore, not need to be designed with any propulsion equipment whatsoever, with the exception at most of a small reserve propulsion system for compensating for possible estimation errors during landing. Of course, instead of a booster /90 rocket, the power could also be supplied in part or entirely by the vehicle itself until the highest horizontal velocity is attained during the ascent. In the former case, it may be advantageous to let the booster rocket strive mainly for a climbing velocity and the vehicle, on the other hand, for a horizontal velocity.

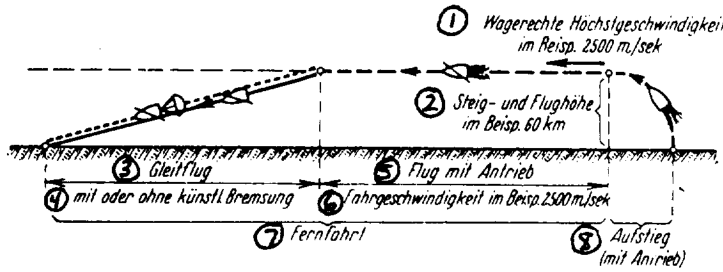


Figure 51. Schematic representation of an "express flight at a cosmic velocity" during which the highest horizontal velocity is not sufficient for covering the entire long-distance trip in glided flight so that a part of the trip must be traveled under power.

Key: 1. Highest horizontal velocity of 2,500 m/sec in the example; 2. Climb and flight altitude of 60 km in the example; 3. Glided flight; 4. With or without artificial braking; 5. Power flight; 6. Velocity of travel of 2,500 m/sec in the example; 7. Long-distance trip; 8. Ascent (with power).

In the case of a still smaller highest horizontal velocity, a certain part of the long-distance trip would also have to be traveled under power (Figure 51). Regardless how the ascent may take place, it would be necessary in any case that the vehicle be also equipped with a propulsion system and carry as much fuel as is necessary for the duration of the powered flight.

Assuming that benzene and liquid oxygen are used as a /91
fuel and a related exhaust velocity of 2,500 meters per second is attained, then in accordance with the previously

described basic laws of rocket flight technology[20] and for the purpose of attaining the most favorable efficiency, even the travel velocity (and accordingly the highest horizontal velocity) would have to be just as great during the period when power is being applied, that is, 2,500 meters per second. The correspondingly best flight altitude presumably for this flight would be around 60 km, taking Hohmann's landing procedure into account. At this velocity, especially when the trip occurs opposite to the Earth's rotation (from east to west), the effect of centrifugal force would be so slight that the wings would be stressed with almost the entire weight of the vehicle; the trip from now on would almost be only a pure heavier-than-air flight movement rather than celestial body motion.

Taking the lack of sufficient technical documentation into account, we want to ignore for the time being discussing in more detail the design implementation of an express airplane powered by reaction (effect of rockets). This will then only be possible in reality – as was indicated previously[21] vis-a-vis the space rocket in general –, when the basic question of rocket motors is once solved in a satisfactory manner for all practical purposes.

On the other hand, the operating characteristics, which would have to be used here, can already be recognized in substance today. The following supplements the points already discussed about these characteristics:

Since lifting the vehicle during the ascent to very /92
substantial flight altitudes (35 - 75 km) would require a not insignificant expenditure of fuel, it appears advisable to avoid intermediate landings in any case. Also, the condition supports this point that breaking up the entire

---

[20] See Page 29.

[21] See Page 72.

travel distance would make the application of artificial braking necessary to an increasing extent due to the shortening caused as a result of those air distances which can be covered in one flight; these intermediate landings, however, mean a waste of valuable energy, ignoring entirely the losses in time, inconveniences and increasing danger always associated with them. It is inherent in the nature of express flight transportation that it must be demonstrated as being that much more advantageous, the greater (within terrestrial limits, of course) the distances to be covered in one flight are, so that these distances will still not be shortened intentionally through intermediate landings.

Consequently, opening up intermediate filling stations, for example, as has already been recommended for the rocket airplane, among others, by analogy with many projects of transoceanic flight traffic, would be completely counter to the characteristic of the rocket airplane. However, it is surely a false technique to clarify these types of motion by simply taking only as a model the travel technology of our current airplanes, because rocket and propeller vehicles are extremely different in operation, after all.

On the other hand, however, we consider it equally incorrect that rocket airplane travel should proceed not as an actual "flight" at all, but primarily more as a throw (similar to what was discussed in the earlier section), a point supported by many authors. Then in this case, a vertical travel velocity component, including the horizontal one, can be slowed down during the descent of the vehicle. Due to the excessively short length of vertical braking distance possible at best in the Earth's atmosphere, this velocity component, however, cannot be nullified by means of air drag, but only through reaction braking. Taking the related large fuel consumption into account, the latter, however, must be avoided if at all possible.

The emergence of a prominent vertical travel velocity component must, for this reason, be inhibited in the first place, and this is accomplished when, as recommended by the author, the trip is covered without exception as a heavier-than-air flight in an approximately horizontal flight path – where possible, chiefly in glided flight (without power) –; that is, proceeding[22] similarly to the last stage of Hohmann's glided flight landing which, in our case, is started from scratch, and more specifically, at the highest horizontal velocity. /93

The largest average velocity during the trip, at which a given distance could be traveled in the first place during an express flight of this type, is a function of the length of this distance. The travel velocity is limited by the requirement that braking of the vehicle must still be successful for landing when it is initiated as soon as possible, that is, immediately after attaining the highest horizontal velocity (Figure 52).

The "best case highest horizontal velocity" for a given distance would be that which just suffices for covering of the entire trip in glided flight to the destination without significant artificial braking (Figures 50 and 53). In the opinion of the author, this represents without a doubt the most advantageous operating characteristics for a rocket airplane. In addition, it is useable for all terrestrial distances, even the furthest, if only the highest horizontal velocity is appropriately selected, primarily since a decreased travel resistance is also achieved at the same time accompanied by an increase of this velocity, because the greater the horizontal velocity becomes, the closer the flight approaches free orbital motion around the Earth and consequently the vehicle loses weight due to a stronger

---

[22] On this point, reference what was described on Pages 93 and 94.

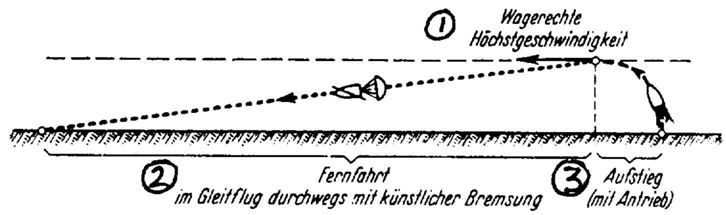


Figure 52. The highest average velocity during the trip is attained when the highest horizontal velocity is selected so large than it can just be slowed if artificial braking is started immediately after attaining that velocity. (In the schematic representations of Figures 49 through 52, the Earth's surface would appear curved in a true representation, exactly as in Figure 53.)

Key: 1. Highest horizontal velocity; 2. Long-distant trip in glided flight completely with artificial braking; 3. Ascent (with power).

occurrence of centrifugal force. And the less lift is necessary by the atmosphere, such that the flight path can now be repositioned to correspondingly higher, thinner layers of air with less drag – also with a lower natural braking effect.

The magnitude of the best case highest horizontal velocity is solely a function of the length of the distance to be traveled; however, this length can only be specified exactly when the ratios of drag in the higher layers of air are studied at supersonic and cosmic velocities.

However, even smaller highest horizontal velocities, at /95
which a part of the trip would have to be traveled (investigated previously for benzene propulsion), could be considered on occasion. Considerably greater velocities, on the other hand, could hardly be considered because they would make operations very uneconomical due to the necessity of having to destroy artificially a significant portion of the energy expended through parachute braking.

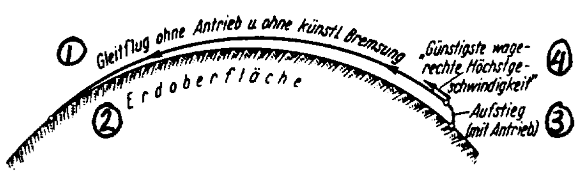


Figure 53. The most advantageous way of implementing an "express flight at a cosmic velocity" is as follows: The highest horizontal velocity is – corresponding to the distance – selected so large ("best case highest horizontal velocity) that the entire long-distance trip can be made in glided flight without power and without artificial braking (see Figure 50 for a diagram).

Key: 1. Glided flight without power and without artificial braking; 2. Earth's surface; 3. Ascent (with power); 4. "Best case highest horizontal velocity".

It turns out that these greater velocities are not even necessary! Then, when employing the "best case" highest horizontal velocities and even when employing the lower ones, every possible terrestrial distance, even those on the other side of the Earth, could be covered in only a few hours.

In addition to the advantage of a travel velocity of this magnitude which appears almost enormous even for today's spoiled notions is the advantage of the minimal danger with such an express flight, because during the long-distance trip, unanticipated "external dangers" cannot occur at all: that obstacles in the flight path occur is, of course, not possible for all practical purposes, as is the case for every other air vehicle flying at an appropriately high altitude. However, even dangers due to weather, which can occasionally be disastrous for a vehicle of this type, especially during very long-distance trips (e.g., ocean crossings), are completely eliminated during the entire trip for the express airplane, because weather formation is limited only to the lower part of the atmosphere stretching up to about 10 km – the so-called "troposphere." The part of the atmosphere above this altitude – the "stratosphere" – is completely free of weather; express flight transportation would be carried out within this layer. Ignoring the always constant air streams, there are no longer any atmospheric changes whatsoever in the stratosphere.

Furthermore, if the "best case highest possible velocity" is employed such that neither power nor artificial braking is necessary during the long-distance trip, then the "internal dangers" (ones inherent in the functioning of the vehicle) are reduced to a minimum. Just like external dangers, internal ones can only occur in the first place during ascent and landing. As soon as the latter two are /96
mastered at least to that level of safety characteristic for other means of transportation, then express airplanes powered by reaction will not only represent the fastest possible vehicles for our Earth, but also the safest.

Achieving a transportation-engineering success of this magnitude would be something so marvelous that this alone would justify all efforts which the implementation of space flight may yet demand. Our notions about terrestrial distances, however, would have to be altered radically if we are to be able to travel, for example, from Berlin to Tokyo or around the entire globe in just under one morning! Only then will we be able to feel like conquerors of our Earth, but at the same time justifiably realizing how small our home planet is in reality, and the longing would increase for those distant worlds familiar to us today only as stars.

## The Space Station in Empty Space

Up to this point, we have not even pursued the actual purpose of space ship travel. The goal with initially this purpose in mind would now be as follows: to ascend so high that we arrived correspondingly high above the Earth's atmosphere into completely empty space, without having to separate completely form the Earth ahead of time, however. Solely as a result of this effort, tremendous, entirely new vistas would open up.

Nevertheless, it is not sufficient in this regard to be able only to ascend and to land again. No doubt, it should be possible to perform many scientific observations during the course of the trip, during which the altitude is selected so high that the trip lasts days or weeks. A large-scale utilization of space flight could not be achieved in this fashion, however. Primarily because the necessary equipment for this purpose cannot be hauled aloft in one trip due to their bulk, but only carried one after the other, component-by-component and then assembled at the high altitude.

The latter, however, assumes the capability to be able /97
to spend time, even arbitrarily long periods, at the attained altitude. This is similar, for instance, to a captive balloon held aloft suspended for long periods without any expenditure of energy, being carried only by the lift of the atmosphere. However, how would this be possible in our case at altitudes extending up into empty space where nothing exists? Even the air for support is missing. Yet nevertheless! Even when nothing material is available, there is nevertheless something available to keep us up there, and in particular something very reliable. It is an entirely natural phenomenon: the frequently discussed centrifugal force.

Introductory paragraphs[23] indicated that mankind could escape a star's gravitational effect, not only by reaching the practical limit of gravity, but also by transitioning into a free orbit, because in the latter case the effect of gravity is offset by the emerging forces of inertia (solely by the centrifugal force in a circular orbit, Figure 5),

---

[23] See Pages 6 through 11.

such that a stable state of suspension exists which would allow us to remain arbitrarily long over the star in question. Now in the present case, we also would have to make use of this possibility.

Accordingly, it is a matter of not only reaching the desired altitude during the ascent, but also of attaining a given orbital velocity exactly corresponding to the altitude in question (and/or to the distance from the Earth's center). The magnitude of this velocity can be computed exactly from the laws of gravitational motion. Imparting this orbital velocity, which in no case would have to be more than around 8,000 meters per second for the Earth, would present no difficulties, as soon as we have progressed to the point where the completed space vehicle is capable of ascending at that rate.

Considering the infinitely large number of possible /98 free orbits around the Earth, only the ones having significance for our present purpose are approximately circular and of these only those are of particular interest whose radius (distance from the center of the Earth) is 42,300 km (Figure 54). At an assigned orbiting velocity of 3,080 meters per second, this radius corresponds to an orbital angular velocity just as great as the velocity of the Earth's rotation. That means nothing other than that an object circles the Earth just as fast in one of these orbits as the Earth itself rotates: once per day ("stationary orbit").

Furthermore, if we adjust the orbit in such a fashion that it is now exactly in the plane of the equator, then the object would continually remain over one and the same point on the equator, precisely 35,900 km above the Earth's surface, when taking into account the radius of the Earth of around 6,400 km (Figure 54). The object would then so to speak form the pinnacle of a enormously high tower which would not even exist but whose bearing capacity would be

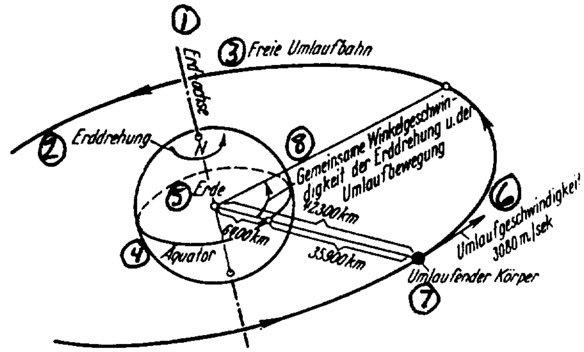


Figure 54. Each object orbiting the Earth in the plane of the equator, 42,300 km from the center of the Earth in a circular orbit, constantly remains freely suspended over the same point on the Earth's surface.

Key: 1. Earth's axis; 2. Earth's rotation; 3. Free orbit; 4. Equator; 5. Earth; 6. Orbital velocity of 3,080 m/sec; 7. Orbiting object; 8. Common angular velocity of the Earth's rotation and of the orbital motion.

replaced by the effect of centrifugal force (Figure 55).

This suspended "pinnacle of the tower" would now be completed up to any height and equipped appropriately. An edifice of this type would arise, fixed to the Earth and even continually remaining in a constant position in relationship to the Earth, and located far above the atmosphere in empty space: a space station at an "altitude /99
of 35,900,000 meters above see level." If this "space station" would have been built in the meridian of Berlin, for example, then from there it could continually be seen at that position in the sky where the sun is located at noon in the middle of October.

If, instead of over the equator, the space station is to be positioned over another point on the Earth, we then, however, would have to forego being able to maintain it in a constant position in relation to the Earth's surface, because it would be necessary in this case to impart to the plane of its orbit an appropriate angle of inclination opposite to the plane of the equator, something which,

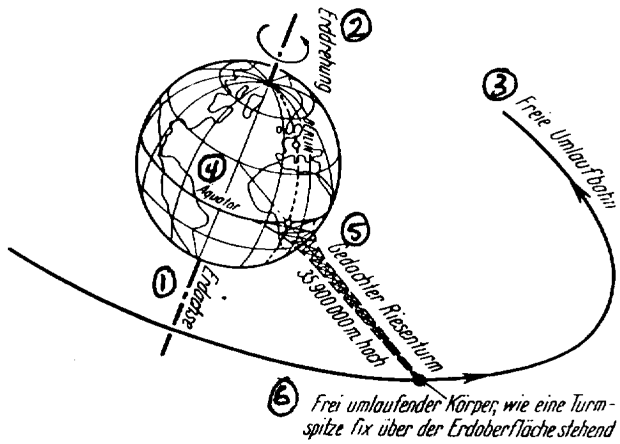


Figure 55. An object orbiting the Earth as in Figure 54 behaves as if it would form the pinnacle of a enormously giant tower (naturally, only imaginary) 35,900,000 meters high.

Key: 1. Earth's axis; 2. Earth's rotation; 3. Free orbit; 4. Equator; 5. Imaginary giant tower 39,000,000 meters high; 6. Freely orbiting object, like a pinnacle of a tower, remaining fixed over the Earth's surface.

depending on the magnitude of this angle of inclination, would lead to the space station oscillating more or less deeply during the course of the day from the zenith toward the horizon. This disadvantage could, however, be compensated for in part when not only one but many space stations were built for a given location; with an appropriate selection of the orbital inclination, it would then be possible to ensure that always one of the space stations is located near the zenith of the location in question.

Finally, the special case would be possible in which the orbit is adjusted in such a manner that its plane remains either vertical to the plane of the Earth's orbit, as suggested by Oberth, or to that of the equator.

In the same manner, the extent (the diameter) of the orbit could naturally be selected otherwise than that /100
selected in the present case for the purpose of attaining

the stationary orbit: for example, if the orbit is supposed to occur for energy efficiency reasons at a greater distance from the Earth (transportation station, see the following) or closer to it, and/or if continually changing the orientation of the space station in relation to the Earth's surface would be especially desired (if necessary, for a space mirror, mapping, etc, see the following).

Now how would life be lived in a space station, what objectives could it serve and consequently how would it have to be furnished and equipped? The special physical conditions existing in outer space, weightlessness and vacuum, are critical for these questions.

### The Nature of Gravity and How it can be Influenced

The beginning of this book discussed[24] the so-called inertial forces and showed that we distinguished several types of these forces: gravity, inertia and, as a special case of the latter, centrifugal force. At this point, we must concern ourselves in somewhat more detail with their nature.

Their nature exists in the fact that these forces do not act only upon individual points of the surface of the object like other mechanical forces, but that they act simultaneously on all points even its internal ones. Since this special characteristic feature is common to all inertial forces, it is, therefore, entirely immaterial as far as a practical effect is concerned the type of inertial force. Like the force of gravity, it will always affect a object in the same fashion, and we will likewise feel it in every case as the well-known "weighty feeling," regardless

---

[24] See Pages 1 through 4.

whether the force is gravity, inertia, centrifugal force or even the result of many of these forces. As a result of this complete uniformity of effect, it is possible that different types of inertial forces can mutually strengthen or weaken or also completely offset each other. /101

We are already familiar with an example of the occurrence of a mutual strengthening of inertial forces when studying the ascent of space rockets[25]. In this case, the force of gravity is increased due to the resulting emerging inertia as long as there is power, something which makes itself felt for all practical purposes like a temporary increase of the force of gravity (Figure 22). /102

However, even under normal terrestrial conditions, the state of an increased force of gravity – and even for a randomly long duration – can be produced, when the centrifugal force is called upon for this purpose. Applied in an engineering sense, the latter takes place, for example, in different types of centrifuges and would be accomplished even on a large scale using a carrousel built especially for this purpose (Figure 56) or better yet by means of specially-built giant centrifuges (Figures 57 and 58). At an appropriately high rate of rotation, a very significant multiplication of the gravitational effect would be achievable in this fashion.

On the other hand, a longer lasting decrease or offsetting of gravity (that is, generating a lasting weightless state) is not possible under terrestrial conditions, because – to emphasize once again – the force of gravity cannot be disabled in any other way whatsoever other than through the opposition of another inertial force of the same magnitude. Therefore, an object can be prevented by supports from falling (complying with the force of gravity). Its weight, however, cannot be offset as a result, a point

---

[25] See Pages 41 and 43.

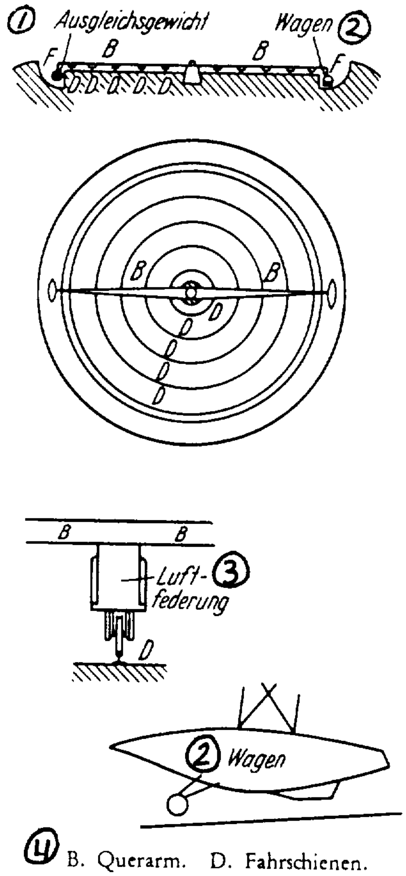


Figure 56. Carousel in accordance with Oberth. This equipment and that shown in Figure 57 are both designed to produce artificially the condition of an increased force of gravity for the purpose of carrying-out physiological experiments.

Key: 1. Counterbalancing weight; 2. Car; 3. Pneumatic cushioning; 4. B Lateral arm; D. Tracks.

proven by the continual presence of its pressure on the support. Even the experiment to remove the influence of the force of gravity from an object, for instance, by any change of its material structure, would, no doubt, be condemned as a failure for all times.

However, on the Earth's surface neither a correspondingly strong alien force of gravity is available nor can centrifugal forces be activated in an object in such /103

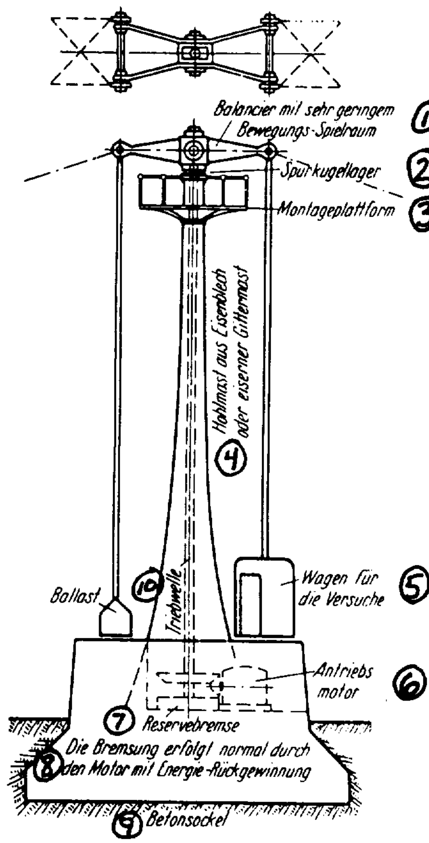


Figure 57. Giant centrifuge in accordance with the author's recommendation. This equipment and that shown in Figure 56 are both designed to produce artificially the condition of an increased force of gravity for the purpose of carrying-out physiological experiments.

Key: 1. Cartwright beam with a slight clearance of motion; 2. Circular ball bearing; 3. Maintenance platform; 4. Tubular pole made from sheet iron or iron lattice tower; 5. Car for the experiments; 6. Drive motor; 7. Back-up braking; 8. Braking occurs normally by the motor using energy recovery; 9. Concrete base; 10. Drive shaft.

a way that it is transposed into an observable weightless state as a result of their effect.

No doubt, it is, however, possible on the Earth – only for a short duration, however – to offset the force of gravity through the third inertial force: by means of inertia. Every day, we can experience this type of

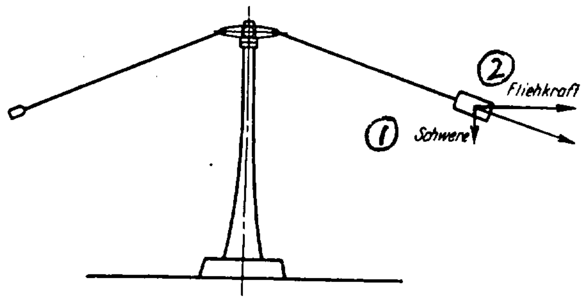


Figure 58. The giant centrifuge in operation.

Key: 1. Gravity; 2. Centrifugal force.

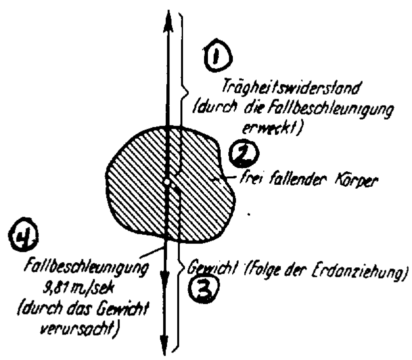


Figure 59. The interplay of forces on a free falling object.

Key: 1. Inertia (activated by the acceleration due to gravity); 2. Free falling object; 3. Weight (as a result of the Earth's attraction); 4. Acceleration due to gravity of 9.81 m/sec$^2$ (caused by the weight).

occurrence of weightlessness on ourselves or observe it on other objects: in the free fall state. That an object falls means nothing more than that it is moved towards the center of the Earth by its weight, and more specifically, at an acceleration (of 9.81 m/sec$^2$, a value familiar to us) which is exactly so large that the inertia activated in the object as a result exactly offsets the object's weight (Figure 59), because if a part of this weight still remained, then it would result in a corresponding increase of the acceleration and consequently of the inertia (opposing gravity in this case).

In the free fall or during a jump, we are weightless according to this. That feeling which we experience during the fall or jump is that of weightlessness; that behavior which we observe in an object during free fall would also be demonstrated in a weightless state generated in another way. Since, however, falling can only last moments if it is not supposed to lead to destruction (the longest time when /104
parachute jumping, ski jumping, etc.), then the occurrence of the weightless state on Earth is possible for only a very short time. Nevertheless, Oberth was successful in conducting very interesting experiments in this manner, from which conclusions can be made about the behavior of various objects and about the course of natural phenomena in the weight-free state.

Completely different, however, are the conditions during space travel. Not only can free fall last for days and weeks during space travel, it would also be possible to remove permanently the effect of gravity from an object: more specifically and as already stated in the introductory material[26] by using the opposite effect from the inertial forces produced by free orbital motion, in particular, from the centrifugal force. According to what has been previously stated, the space station can also make use of this. Consequently, it is in the state of complete freedom from gravity lasting indefinitely ("a stabile state of suspension").

## The Effect of the Freedom from Gravity on the Human Organism

How does the absence of gravity effect the human organism? The experience during free fall shows that a

---

[26] See Pages 6 and 8.

state of weightlessness lasting only a short time is not dangerous to peoples' health. Whether this, however, would be true in the case of a long-lasting freedom from gravity cannot be predicted with certainty because this condition has not been experienced by anyone. Nevertheless, it may be assumed with a high probability, at least in a physiological sense, because all bodily functions occur through muscular or osmotic forces not requiring the help of gravity. In actuality, all life-giving processes of the bodily state have been shown as completely independent and are carried out just as well in a standing, in a lying or in any other position of the body.

Only for very long periods in a weightless state could /105
a definite injury be experienced, perhaps by the fact that important muscle groups would atrophy due to continual disuse and, therefore, fail in their function when life is again evolving under normal gravitational conditions (e.g, following the return to Earth). However, it is probable that these effects could be counteracted successfully by systematic muscular exercises, ignoring the fact that it also would be possible to make allowance for these conditions by means of appropriate technical precautions, as we will see later.

Apparently, the only organ affected by the absence of gravity is the organ of equilibrium in the inner ear. However, it is no longer required in the same sense as otherwise, because the concept of equilibrium after all ceases to exist in the weightless state. In every position of the body, we have then the same feeling: "up" and "down" lose their usual meaning (related to the environment); floor, ceiling and walls of a room are no longer different from one another.

However in the beginning at least, the impression of this entirely unusual condition may cause a strongly negative psychological effect. Added to this is the effect which is directly exercised on the nervous system by the weightless state. The most important related sensations to this effect are as follows: the previously discussed effect on the organ of equilibrium, cessation of the perception of a supporting pressure against the body, and certain changes in the feelings in the muscles and joints.

However up to the present time, this complex of feelings is known to us only from the free fall state because we, as already discussed, can experience freedom from gravity under terrestrial conditions only during falling; involuntarily, we will, therefore, feel anxiety /106 related to the falling, as well as other psychological states aroused by this unusual situation during a cessation of the feeling of gravity, when the freedom of gravity is not even caused by falling, but in another way (such as, in the space station by the effect of centrifugal force).

However, it can be expected based on previous experiences (pilots, ski jumpers, etc.) that it will be possible through adaptation to be able to easily tolerate the weightless state even in a psychological sense. Adapting occurs that much sooner, the more mankind is familiar with the fact that "weightless" and "falling" need not be related to one another. It can even be assumed that anxiety is altogether absent during a gradual release from the feeling of gravity.

Oberth has addressed all of these issues in depth. By evaluating his results, they can be summarized as follows: while weightlessness could certainly be tolerated over a long time, although perhaps not indefinitely, without significant harm in a physical sense, this cannot be stated with certainty in a psychological sense, but can be assumed as probable none the less. The course of the psychological impressions apparently would more or less be the following: in the beginning – at least during a rapid, abrupt occurrence of the freedom from gravity – anxiety; the brain and senses are functioning extremely intensively, all thoughts are strongly factual and are quickly comprehended with a penetrating logic; time appears to move more slowly; and a unique insensitivity to pains and feelings of reluctance appear. Later, these phenomena subside, and only a certain feeling of elevated tension and physical fitness remain, perhaps similar to after taking a stimulant; until finally after a longer period of adaptation, the psychological state possibly becomes entirely normal.

## The Physical Behavior of the Body when Gravity is Missing /107

In order to be able to form a concept of the general physical conditions existing in a weightless state, the following must be noted: the force of the Earth's gravity pulling all masses down to the ground and thus ordering them according to a certain regularity is no longer active. Accordingly almost following only the laws of inertia (power of inertia), bodies are moving continually in a straight line in their arbitrary direction of motion so long as no resistance impedes them, and they are oriented solely towards the forces (molecular, electrical, magnetic, mass-attracting and others) acting among and in them and reaching the bodies themselves.

These unusual conditions must, however, lead to the result that all bodies demonstrate a completely altered behavior and that, in accordance with this behavior, our unique actions and inactions will develop in a manner entirely different from previous ones.

Therefore, human movement can now no longer occur by "going." The feet have lost their usual function. In the absence of the pressure of weight, friction is missing under the soles; the latter stick, therefore, considerably less to the ground than even to the smoothest sheet of ice. To move, we must either pull ourselves along an area with our hands (Figure 60, z), for which purpose the walls of the space station would have to be furnished with appropriate handles (for instance, straps similar to those of street cars) (Figures 60 and 61), or push ourselves off in the direction of the destination and float towards it (Figure 60, a).

It will probably be difficult for the amateur to maintain an appropriate point of reference with his energies. This, however, is necessary: since he impacts the opposite wall of the room with the full force of pushing off, too much zeal can lead very easily in this case to /108
painful bumps. For this reason, the walls and in particular all corners and edges would have to be very well cushioned in all rooms used by human beings (Figure 60).

Pushing off can also be life threatening, more /109
specifically, when it occurs not in an enclosed room but in the open; e.g., during a stay (in the space suit, see the following) outside of the space station, because if we neglected to take appropriate precautionary measures in this case and miss our destination while pushing off, then we would continually float further without end into the deadly vacuum of outer space. The no less terrible possibility of "floating off into space" now threatens as a counterpart to the terrestrial danger of "falling into the depths." The saying "man overboard" is also valid when gravity is missing, however in another sense.

Since bodies are now no longer pressed upon their support by their weight, it, of course, has no purpose that an item is "hung up" or "laid down" any place, other than it would stick to its support or would be held down by magnetic or other forces, for instance. An object can now only be stored by attaching it somewhere or better yet locking it up. Therefore, the rooms of the space station would have to be furnished with reliably lockable small chests conveniently placed on the walls (Figures 60 and 61, K).

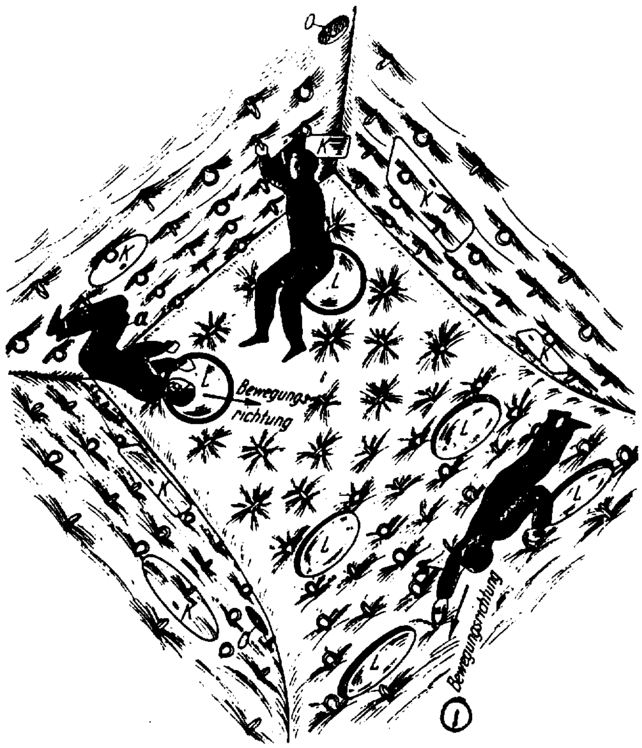


Figure 60. A room of the space station in which a weightless state exists and which is furnished accordingly: The walls are completely cushioned and equipped with straps. No loose object is present.

K ....... Lockable small chests for holding tools and similar items.
L ....... Openings for admitting light (reference Page 143).
O ....... Openings for ventilation (reference Page 144).
z ....... Movement of people by pulling.
a ....... Movement of people by pushing off.

Key: 1. Direction of motion.

Clothes racks, shelves and similar items, even tables, as far as they are meant to hold objects, have become useless pieces of furniture. Even chairs, benches and beds can no longer satisfy their function; humans will have to be tied to them in order not to float away from them into any corner of the room during the smallest movement. Without gravity, there is neither a "standing" nor a "sitting" or "lying." In order to work, it is, therefore, necessary to be secured to the location of the activity: for example, to the table when writing or drawing (Figure 61). To sleep, we do not have to lie down first, however; we can take a rest in any body position or at any location in the room.

/110

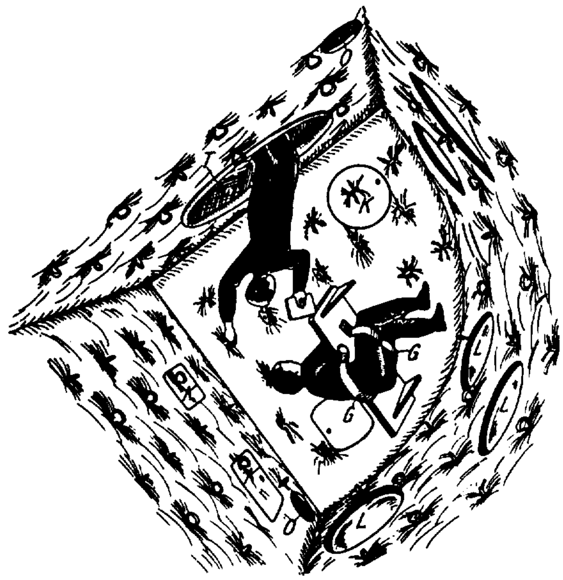

Figure 61. Writing in the weightless state: for this purpose, we have to be secured to the tabletop, for example, by means of leather straps (G) in order to remain at the table at all (without having to hold on). – A man floats in from the next room through the (in this case, round) door opening, bringing something with him.

However, despite this irregularity in the physical behavior of freely moving objects caused by the absence of gravity, the manner is actually not completely arbitrary as to how these objects now come to rest. The general law of mass attraction is valid even for the space station itself and causes all masses to be attracted toward the common center of mass; however – due to the relative insignificance of the entire mass – they are attracted at such an extremely slight acceleration that traveling only one meter takes hours. However, non-secured objects will finally impact one of the walls of the room either as a result of this or of their other random movement, and either immediately remain on this wall or, if their velocity was sufficiently large, bounce back again and again among the walls of the room depending on the degree of elasticity, floating back and forth until their energy of movement is gradually expended and they also come to rest on one of the walls. Therefore, all objects freely suspended within the space station will land on the walls over time; more specifically, they will approach as close as possible to the common center of mass of the structure.

However, since this phenomenon can extend over hours, /111
sometimes over many days, and even a weak air draft would suffice to interfere with it and/or to tear objects away from the wall, which are already at rest but only adhering very weakly, and to mix them all up, then as a result no regularity is applied to the type of motion of weightless masses from a practical point of view.

The latter is felt especially unpleasantly when objects are in one room in significant numbers. If these objects are dust particles, they can be collected and removed in a relatively easy manner, more specifically, by filtering the air by means of vacuum cleaners or similar devices. However, if they are somewhat bigger as, for example, carelessly emptying a sack of apples into a room, then the only alternative would be trapping them by means of nets. All objects must be keep in a safe place, because the ordering power of gravity now no longer exists: matter is "unleashed."

Also, clothing materials are also on strike, because they no longer "fall," even if they were made of a heavy weave. Therefore, coats, skirts, aprons and similar articles of clothing are un-useable pieces of clothing. During body movements, they would lay totally irregularly in all possible directions.

The behavior of liquids is especially unique in a weightless state. As is well known, they try under normal conditions to attain the lowest possible positions, consequently obeying gravity by always clinging completely to the respective supports (to the container, to the ground, etc.). If gravity is missing, however, the individual particles of mass can obey their molecular forces unimpeded and arrange themselves according to their characteristics.

In the weightless state therefore, liquids take on an /112
independent shape, more specifically, the simplest geometric shape of an object: that of a ball. A prerequisite for this is, however, that they are subjected to only their cohesion forces; that is, they are not touching any object which they can "moisten."

It now becomes understandable why water forms drops when falling. In this state, water is weightless, according to what has been previously stated; it takes on the shape of a ball which is distorted to the form of a drop by the resistance of air, however.

However, if the liquid is touching an object by moistening it, then cohesion and adhesion forces appear of overwhelming strength. The liquid will then strive to obey these forces, spreading out as much as possible over the surface of the object and coating it with a more or less thick layer of liquid.

Accordingly for example, water in only a partially filled bottle will, for instance, not occupy the bottom of the bottle, but, leaving the center empty, attempts to spread out over all the walls of the container (Figure 62). On the other hand, mercury, which is not a moistening liquid, coalesces to a ball and adheres to one wall of the container, remaining suspended in the bottle (Figure 63).

In both instances, the position of the body is /113
completely immaterial. Therefore, the bottle cannot be emptied by simply tilting it, as is usually the case. To

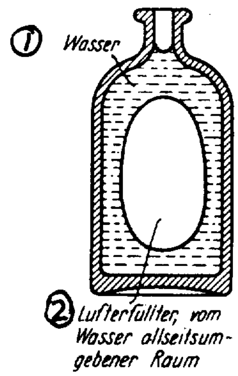


Figure 62. Dispersion of water in only a partially filled bottle in the absence of gravity.

Key: 1. Water; 2. An air-filled space surrounded on all sides by water.

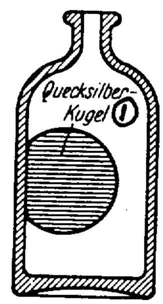


Figure 63. Behavior of mercury in a bottle in the absence of gravity.

Key: 1. Ball of mercury.

achieve this effect, the bottle must be: either pulled back rapidly (accelerated backwards, Figure 64) or pushed forward in the direction of the outlet and/or then suddenly halting it in an existing forward motion (slowing it down in a forward movement, also as in Figure 64), or finally swung around in a circle (Figure 65).

The liquid will then escape out of the bottle as a result of its power of inertia (manifested in the latter case as centrifugal force), while imbibing air at the same

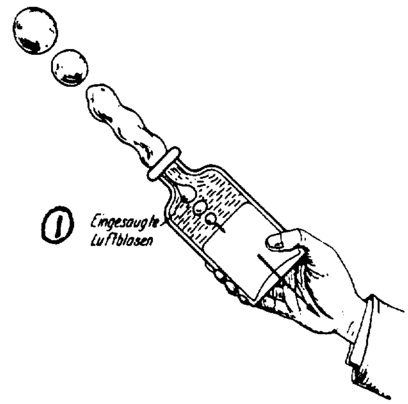


Figure 64. Emptying a bottle in a weightless state by pulling it back.

Key: 1. Imbibing air bubbles.

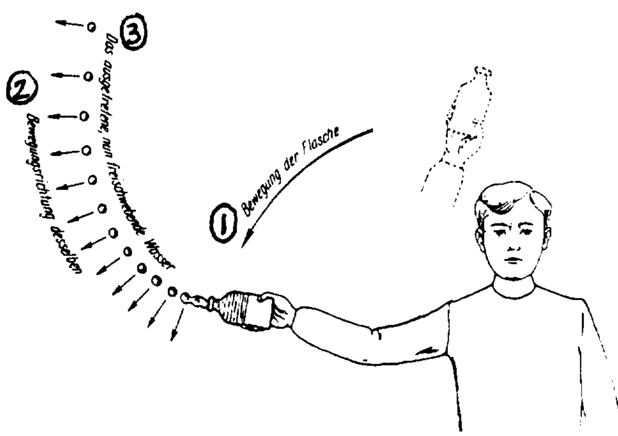


Figure 65. In the absence of gravity, swinging a bottle of water in a circle in order to empty it. (In reality, the escaping liquid will probably not be dispersed in such a regular fashion as the discharge curve indicates.)

Key: 1. Motion of the bottle; 2. Direction of motion of the water; 3. The escaping water now freely suspended.

time (like gurgling when emptying the bottle in the usual fashion). A prerequisite, however, for this is that the neck of the bottle is sufficiently wide and/or the motion is performed with sufficient force such that this entry of air can actually take place against the simultaneous outward flow of water.

[It is interesting to note that strictly speaking the /114
described method of emptying a bottle in the absence of gravity by pulling it back or halting it proceeds in reality none other than if the water is poured out by turning the bottle upside down in the presence of gravity. Of course, these are physical phenomena, completely analogous if the motion of pulling back and/or halting is performed exactly at the acceleration of gravity (9.81 m/sec$^2$ for us), because as is known in accordance with the general theory of relativity, a system engaged in accelerated or decelerated motion is completely analogous to a gravitational field of the same acceleration. In the case of the described method of emptying, it can be stated that at the location where gravity is missing those forces of inertial mass, which are activated by pulling back and/or halting of the system including the bottle and its contents, occur in a replacement sense, so to speak.]

After escaping from the bottle, the liquid coalesces into one or more balls and will continue floating in the room, and may appear similar to soap bubbles moving through the air. Finally, every floating liquid ball of this type must then impact on one of the walls of the room.

If it can moisten one of those walls, then it will try to spread out over them (left portion of Figure 66).

Otherwise as a result of the push, the liquid will /115
scatter into numerous smaller balls, somewhat similar to an impacting drop of mercury. These balls float away along the walls or perhaps occasionally freely through the room, partially coalescing again or scattering once again until their kinetic force has finally been expended and the entire amount of liquid comes to rest, coalesced into one or more balls adhering to the walls (right portion of Figure 66). (In this regard, compare the previous statements about the

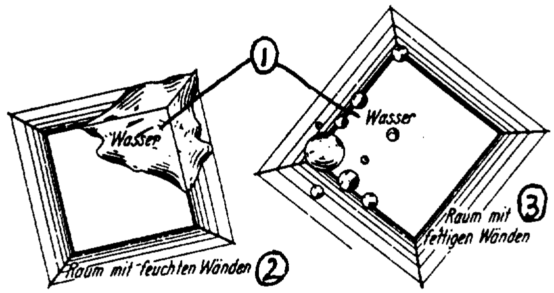


Figure 66. In the absence of gravity, escaping water would spread out over the walls in a room whose walls are easily moistened (e.g., they are somewhat damp) (diagram on the left); in a room whose wall are not easily moistened (e.g., they are greasy), the water coalesces into balls and adheres to the walls (diagram on the right).

Key: 1. Water; 2. Room with damp walls; 3. Room with greasy walls.

phenomena in a bottle, Figures 62 and 63.)

Taking this unusual behavior of the liquid into consideration, none of the typical containers, such as bottles, drinking glasses, cooking pots, jugs, sinks, etc., could be used. It would hardly be possible to fill them. However, even if, by way of example, a bath could be drawn -- we would not be able to take it because in the shortest time and to our disappointment, the water would have spread out of the bathtub over the walls of the room or adhered to them as balls.

For storing liquids, only sealable flexible tubes, rubber balloons or containers with plunger-like, adjustable bottoms, similar to syringes, would be suitable (Figure 67), because only items of this nature can be filled (Figure 68) as well as easily emptied. Containers with plunger-like, adjustable bottoms function by pressing together the sides and/or by advancing the plunger to force out the contents (Figure 69). In the case of elastic balloons, which are filled by expanding the container, the tension on it

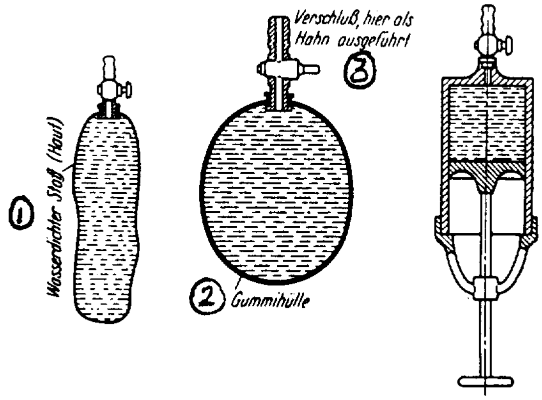


Figure 67. In the absence of gravity, the otherwise usual liquid containers are replaced by sealable flexible tubes (left diagram), rubber balloons (center diagram) or syringe-type containers (right diagram).

Key: 1. Waterproof material (skin); 2. Rubber container; 3. Stopper functioning as a spigot here.

suffices by itself to cause the liquid to flow out when the spigot is opened (Figure 70).

These types of pressure activated containers (fitted /116
with an appropriate mouth piece) would now have to be used for drinking in place of the otherwise typical, but now unusable drinking vessels.

Similarly, the various eating utensils, such as dishes, bowls, spoons, etc., can no longer be used. If we made a careless move, we would have to float through the room chasing after their perhaps savory contents. Eating would, therefore, be possible in the first place only in two ways: either by eating the food in a solid form, such as bread, or drinking it in a liquid or mushy state using the pressure activated containers described above. The cook would also have to deliver the food prepared in this manner.

In this important activity, the cook would be faced with particularly significant problems, however. Nonetheless, they can also be overcome. Thus, the cook

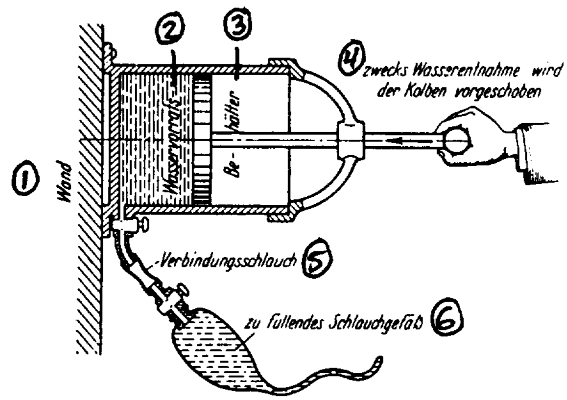


Figure 68. Filling a water vessel in the weightless state.

Key: 1. Wall; 2. Water supply; 3. Container; 4. The plunger is pushed forward for the purpose of removing water; 5. Connecting tube; 6. Tubular container being filled.

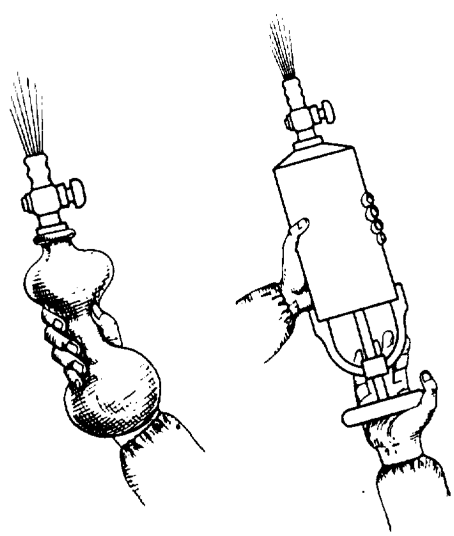

Figure 69. In the absence of gravity, emptying a liquid container can be accomplished in an expedient manner only by pushing out (pressing out) the contents.

could use, for example, sealable electrical cooking appliances, constantly rotating when in use, so that (instead of the now missing gravity) the generated centrifugal force presses the contents against the walls of the container; many other such possibilities could also be used by the cook. In any case, cooking would be very annoying, yet possible in some way just like eating and drinking.

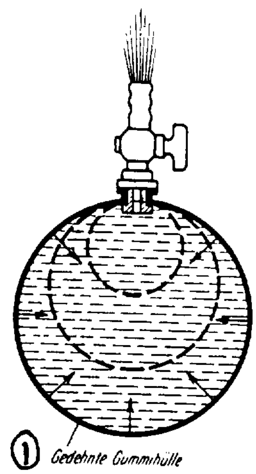


Figure 70. In the case of elastic rubber balloons filled under pressure, the contents flow out of their own accord when the spigot is opened.

Key: 1. Expanded rubber container.

Washing and bathing as we know it would have to be /117
completely done away with, however! Cleaning up is now only able to be accomplished by rubbing with damp towels lathered according to need, sponges or similar items, regardless of how well or badly they may function in this manner.

The more in depth we the consider the matter, the more we must recognize that in reality it would in no way be an entirely obvious pleasure, freed from all bothersome weight, being able to float like angels; no doubt, not even when this state would be perceived as pleasant. Because, gravity not only holds us in her grip, but it also forces all other objects to the ground and inhibits them from moving /118
chaotically, entirely without any regularity and freely abandoned to chance. It is perhaps the most important force for imposing order upon our existence. Where gravity is

absent, everything is in the truest sense "standing on its head," having lost its foothold.

## Without Air

Human life can exist only in the presence of appropriately composed gaseous air: on the one hand, because life is a combustion phenomenon and, therefore, requires for its maintenance a permanent supply of oxygen, which the human organism, however, can only ingest by breathing from gaseous air; and, on the other hand, because the body must always be surrounded by a certain pressure, without which the body's water contents would vaporize and the vessels would burst. It is necessary to provide a man-made supply of air if our terrestrial life is supposed to be possible in empty space.

To accomplish this, people in empty space must always be surrounded on all sides by closed, completely airtight enclosures, because only within such surroundings can the air be artificially maintained at the appropriate pressure and in a correct composition, more specifically, by using self-activating equipment.

In substance, we are only concerned with larger enclosed spaces extending from the size of a closet up to the size of an entire building, because they alone would be possible for a longer stay. The walls of these structures would have to be built in accordance with the fundamentals of steam boiler construction because they have to withstand an internal air overpressure (compared to empty space) of 1 atmosphere; they should not only have an appropriate strength but have only curved surfaces if at all possible, because flat ones require a special brace or support when taking the overpressure into account. The nitrogen necessary for the artificial preparation of air and especially the oxygen would always have to be maintained in sufficient supply in the fluid state in their own tanks and continually refilled by resupplying from Earth.

However, in order to remain outside of enclosed spaces /119 of this type in empty space, airtight suits would have to be employed, whose interior is also supplied automatically with air by devices taken along outside: equipment quite similar to the familiar underwater diving suits. We will call them "space suits." The subject of space suits will be addressed in more detail later.

It can be seen that the present process is concerned with techniques similar to remaining under water, that is, with submarine technology and diving characteristics. On the basis of the extensive experiences already collected for these disciplines vis-a-vis the question of supplying air artificially, it can be stated that this issue is without question entirely solvable even for a stay in empty space.

## Perpetual Silence Exists in Empty Space

Nevertheless, air does not only have direct value for life. Indirectly, it also has an important significance because to a far-reaching extent it influences natural phenomena which are extremely important for the development of life: heat, light and sound.

Sound is a vibrational process of air and can, therefore, never exist in the absence of the latter. For this reason, a perpetual silence exists in empty space. The most massive cannon could not be heard when fired, not even in its immediate vicinity. Even normal voice communication would be impossible. Of course, this does not apply for the enclosed, ventilated spaces, within which the same atmospheric conditions will be maintained artificially as on the Earth's surface; it is applicable, however, for remaining outside of these spaces (in the space suit).

Outside, voice communication could only be possible via telephones.

## Sunshine during Nighttime Darkness /120

However, even the lighting conditions are now considerably altered. As is generally known, the concept of day is associated with the notion of a blue sky or sunlit clouds and scattering of light on all sides, without direct sunlight being necessary. All of these phenomena are, however, due only to the presence of the Earth's atmosphere, because in it a part of the incident rays of the sun is refracted, reflected and scattered in all directions many times as a result, producing at the same time the impression of a blue coloring of the sky. Thus, air produces a manifold pleasant graduation between the harshness of sunlight and darkness.

This is all impossible in empty space because air is absent there. As a result, however, even the concept of day is no longer valid, strictly speaking. Without letup, the sky appears as the darkest black, from which the infinite number of stars shine extremely bright and with a constant soft light, and from which the sun radiates, overwhelming everything with an unimaginably blinding force.

Yet nevertheless: as soon as we avert our gaze from it, we have the impression of night, even though our back is being flooded by its light because, while the side of the object (e.g., an umbrella) turned towards the sun is harshly illuminated under its rays, nighttime darkness exists on the averted side. Not quite complete darkness! After all, the stars shine from all sides and even the Earth or moon as a result of their reflection light up the side of the object in the sun's shadow. In this case, it is only a matter of the harshest, brightest light, never of mild refracted light.

## Unlimited Visibility

In one regard however, the absence of air also has advantages for lighting conditions in empty space. After all, it is generally known what great effect the property of air exerts on visibility (e.g., in the mountains, on the sea, etc.), because even on clear days, a portion of the light beams are always lost in the air and/or through small dust and mist particles constantly suspended in it.

The latter condition is, however, very disadvantageous /121 for performing all types of long range observations, especially those of astronomy. For this reason, observatories are built if at all possible at high altitudes on mountains because there the air is still relatively the clearest. However, restrictions soon result. Furthermore, the flickering of fixed stars, likewise a phenomenon caused only by the presence of air, cannot be constrained at these high locations. In the same manner, it is not possible to eliminate the scattered light (the blue of the sky) which is very bothersome for astronomical observations during the day and which is caused also by the atmosphere, thus making the investigations of those stars very difficult which cannot be seen during complete darkness, such as Mercury, Venus and not least of all the sun itself.

All of these adverse conditions are eliminated in the empty ether space of the universe: nothing now weakens the illuminating power of the stars, the fixed stars no longer flicker, and the blue of the sky no longer interferes with the observations. At any time equally favorable, almost unlimited possibilities present themselves in this case, because telescopes of any arbitrary size, even very large ones, could be used because optical obstructions no longer exist.

## Without Heat

Especially significant is the effect which the absence of air exerts on the thermal conditions of outer space. Because as we know today heat is nothing other than a given state of motion of the smallest material particles from which the materials of objects are structured, their occurrence is always associated with the supposition that materials exist in the first place. Where these materials are missing, heat cannot, therefore, exist: empty space is "heatless" for all practical purposes. Whether this is completely correct from a theoretical standpoint depends on /122
the actual validity of the view expressed by many sides that outer space is filled with a real material, distributed very finely, however. If a total material emptiness exists, then the concept of temperature loses its meaning completely as a result.

This view does not contradict the fact that outer space is permeated to a far-reaching extent by the sun's thermal rays and those of the other fixed stars, because the thermal rays themselves are not yet heat! They are nothing other than electromagnetic ether waves of the same type like, for example, light or sound waves; however, they have a special property in that they can generate, as soon as they impact something material-like, that molecular movement which we call heat. This, however, can only happen when the waves are absorbed (destroyed) by the affected materials during the impacting, because only in this case is their energy transmitted to the object and converted into the object's heat.

Thus, the temperature of a transparent object or of one polished as smooth glass will only be slightly elevated even during intense thermal radiation. The object is almost insensitive to thermal radiation, because in the former case, the rays are for the most part passed through by the object and, in the latter case, the rays are reflected by the object, without being weakened or destroyed, however; i.e., without having to release some part of their energy. If, on the other hand, the surface of the object is dark and rough, then it can neither pass the incident rays through or reflect them: they must be absorbed in this case and cause the body to heat up as a result.

This phenomenon is, however, not only valid for absorption but also for the release of heat through radiation: the brighter and smoother the surface of an object, the less is its ability to radiate and consequently the longer it retains its heat. While, on the other hand, for a dark, rough surface, the object can cool down very rapidly as a result of radiation.

The most matte black and least brightly reflecting /123 surfaces are subjected to the phenomena of thermal radiation of a different type. This condition would make it possible to influence randomly the temperature of objects in empty space in a simple fashion and to a far-reaching extent.

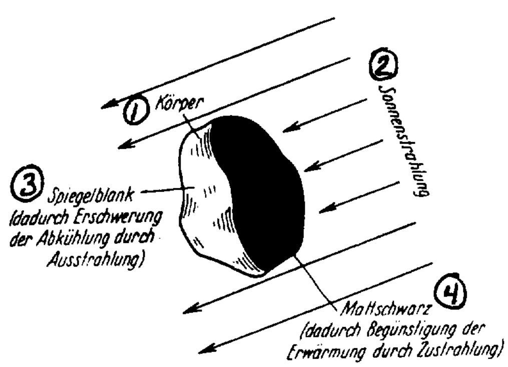


Figure 71. Heating an object in empty space by means of solar radiation by appropriately selecting its surface finish.

Key: 1. Object; 2. Solar radiation; 3. Bank of mirrors (causing cooling to be impeded as a result of radiation); 4. Matte black (causing heating to be promoted as a result of incident radiation).

If an object is to be heated in space, then according to the above discussion its side facing the sun will be made matte black and the dark side brightly reflecting (Figure 71); or the dark side is protected against outer space by means of a mirror (Figure 72). If a concave mirror is used for this purpose, which moreover directs the rays of the sun in an appropriate concentration onto the object, then the object's temperature could be increased significantly (Figure 73).

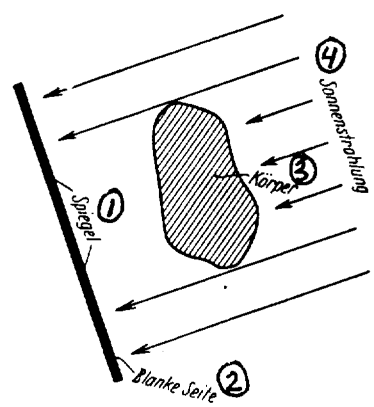


Figure 72. Heating a body by protecting its dark side against empty space by means of a mirror.

Key: 1. Mirror; 2. Polished side; 3. Object; 4. Solar radiation

If, on the other hand, an object is supposed to be cooled down in outer space, then its side facing the sun must be made reflective and its dark side left matte black (Figure 74); or it is protected against the sun by means of a mirror (Figure 75). The object will lose more and more of its heat into space as a result of radiation because the heat can no longer be constantly replaced by conduction from the environment, as happens on the Earth as a result of contact with the surrounding air. On the other hand, supplementing its heat through incident radiation would be /124

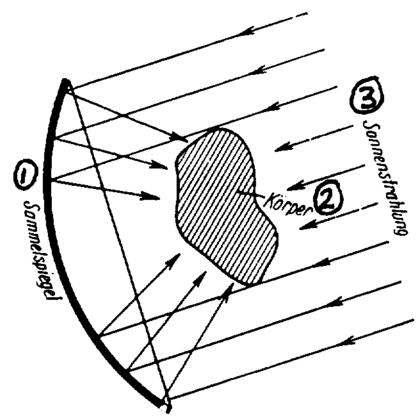


Figure 73. Intensive heating of an object by concentrating the rays of the sun on the object by means of a concave mirror.

Key: 1. Concave mirror; 2. Object; 3. Solar radiation.

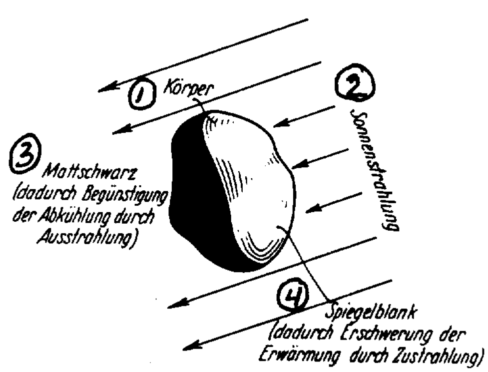


Figure 74. Cooling an object down in empty space by appropriately selecting its surface finish.

Key: 1. Object; 2. Solar radiation; 3. Matte black (causing cooling to be promoted as a result of radiation); 4. Bank of mirrors (causing heating to be impeded as a result of incident radiation).

decreased to a minimum as a result of the indicated screening. In this manner, an object could be cooled down close to absolute zero (-273° Celsius). This temperature could not be reached completely, however, because a given amount of heat is radiated by fixed stars to the object on the dark side, and not even the mirrors could completely protect against the sun.

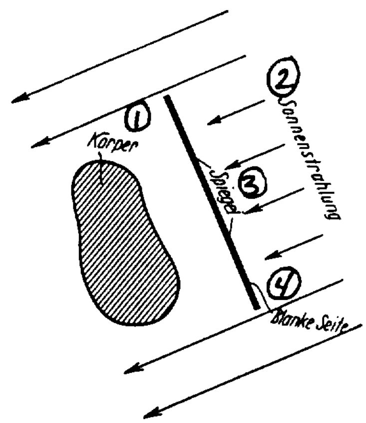


Figure 75. Cooling an object off by protecting it against solar radiation by means of a mirror.

Key: 1. Object; 2. Solar radiation; 3. Mirror; 4. Polished side.

By utilizing the described radiation phenomena, it would, therefore, be possible in the space station to maintain continually not only the normal heat necessary for life, but to produce extremely high and low temperatures and consequently a very significant drop in temperature. /125

## Designing the Space Station

The physical conditions and potentials of empty space are familiar to us now. According, an idea of how our space station would have to be designed is as follows:

In order to simplify the work to be performed if at all possible in outer space when constructing this observatory (this work only being possible in space suits), the entire structure including equipment would have to be entirely erected first on Earth and tested for reliability. Furthermore, it would have to be constructed in such a manner that it could easily be disassembled into its components and if at all possible into individual, completely furnished "cells" which could be transported into outer space by means of space ships and re-assembled there without too many problems. As much as possible, only light-weight metals could be used as materials in order to lower the expenditures of lifting into outer space.

The completed, ready-to-use structure would, in general, resemble the following: primarily, it must be completely sealed externally, airtight against empty space, thus permitting normal atmospheric conditions to be maintained internally in an artificial manner. In order to localize the danger of escaping air, which would happen if a leak occurred (e.g., as a result of an impacting meteor), the space station would be partitioned in an appropriate manner into "bulkheads" familiar from ship building.

Since all rooms are connected with one another and /126 are filled with air, contact is easily possible throughout the inside of the space station. Space travelers can, however, only reach the outside into empty space by means of so-called air locks. This equipment (used in caissons, diving bells, etc.) familiar from underwater construction consists primarily of a small chamber, which has two doors sealed airtight, one of which leads to the inside of the structure and the other to the outside (Figure 76).

By way of example, if the space traveler wants to leave the space station ("outgoing"), then dressed in the space suit he enters the lock through the inside door, the outside door being locked. Now the inside door is locked and the air in the lock is exhausted and/or vented, thus allowing the traveler to open the outer door and float out into the open. In order to reach the inside of the space station ("incoming"), the reverse procedure would have to be followed.

For operations and the related equipment of the space /127 station, it is critical that absolutely nothing is available

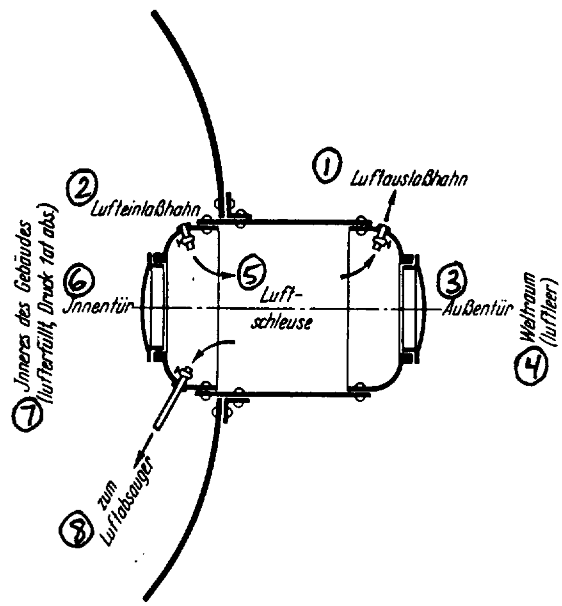


Figure 76. Basic layout of an air lock for travelling between an air-filled room (e.g., the inside of the space station) and empty space. Drawing the air out of the lock during "outgoing" occurs for the most part by exhausting the air into the structure for reasons of economy; only the remaining amount of the air in the lock is blown out into empty space. [Editor's Note: This was footnote 27].

Key: 1. Air outlet spigot; 2. Air intake spigot; 3. Outside door; 4. Outer space (airless); 5. Air lock; 6. Inside door; 7. Inside of the structure (air-filled, pressure of 1 at absolute); 8. To air exhaust

locally other than the rays of the stars, primarily those of the sun – its rays, however, are available almost all the time and in an unlimited quantity. Other substances particularly necessary for life, such as air and water, must be continually supplied from the Earth. From this fact, the following principle obviously results for the operation of the space station: exercise extreme thrift with all consumables, making use instead of the energy available locally in sufficient quantities in the sun's rays to the most far-reaching extent for operating engineering systems of all types, in particular those making it possible to recycle the spent consumables.

## The Solar Power Plant

The solar power plant for the latter purpose (Figure 77) forms, therefore, one of the most all important systems of the space station. It delivers direct current, is equipped with a storage accumulator battery and is comparable in principle to a standard steam turbine complex of the same type. There are the difference, however: the steam generator is now heated with the sun's rays, which are concentrated by a concave mirror for achieving sufficiently high temperatures (Figure 77, D); and cooling the condenser occurs only by radiating into empty space, and thus it must be opened towards empty space and stored protected against the sun (Figure 77, K).

In accordance with our previous explanations, this causes both the steam generator and condenser to be painted matte black on the outside. In substance, both consist solely of appropriately long, continuously curved metal pipes, such that the internal pipe walls even in a /128
weightless state become sufficiently strong from, and are always in contact with, the fuel flowing through them (see Figure 77).

This fuel is in a constant, loss-free circulation. Deviating from the usual case, not water (steam) but a highly volatile medium, more specifically nitrogen, is used in this case as a fuel. Nitrogen allows the temperature of condensation to be maintained so low that the exceptional cooling potential of empty space can in reality be utilized as a result. Furthermore, an accidental escape of nitrogen into the rooms of the space station will not pollute its very valuable air.

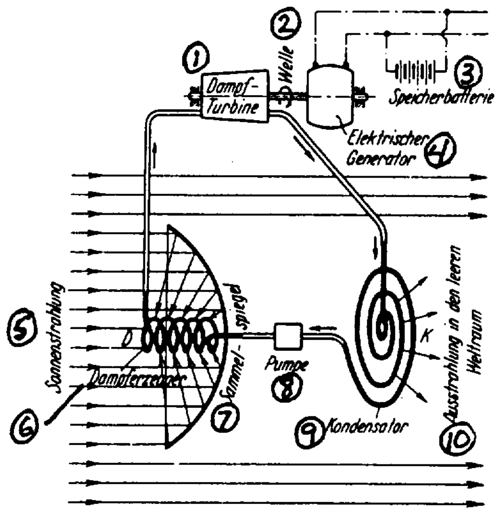


Figure 77. Diagram of the solar power plant of the space station.

Key: 1. Steam turbine; 2. Shaft; 3. Storage battery; 4. Electrical generator; 5. Solar radiation; 6. Steam generator; 7. Concave mirror; 8. Pump; 9. Condenser; 10. Radiating out into empty space.

Since it is only a function of the size of the concave mirror used as to how much energy is being extracted from solar radiation, an appropriately efficient design of the power plant can easily ensure that electrical and mechanical energy at the same time are always plentiful in the space station. Furthermore since heat, even in great amounts, can be obtained directly from solar radiation and refrigeration even down to the lowest temperatures can be generated in a simple fashion by radiating into empty space, the conditions, therefore, exist to be able to operate all types of engineering systems.

## Supplying Light

/129

Lighting the space station can be accomplished the simplest of all because this requires almost no mechanical equipment whatsoever, but can take place for the most part directly as a result of the sun, which shines incessantly, after all – ignoring possible, yet in every case only short, passes by the space station through the Earth's shadow.

For this purpose, the walls have round openings similar to ship's hatches; these openings are glassed in airtight (Figures 60 and 61, L) with strong, lens-type windows (Figure 78). A milk-white coloring and/or matting of the windows and an appropriate selection of the type of glass ensure that sun light is freed of all damaging radiation admixtures, filtered in the same way as through the atmosphere and then enters into the space station in a dispersed state. Therefore, its interior is illuminated by normal daytime light.

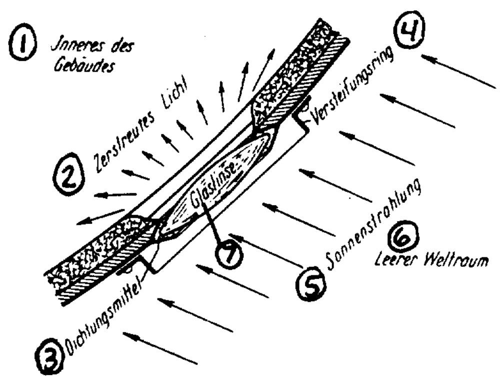


Figure 78. Lighting hatch.

Key: 1. Interior of the structure; 2. Dispersed light; 3. Sealing material; 4. Bracing; 5. Solar radiation; 6. Empty space; 7. Glass lens.

Several of the hatches are fitted with special mirrors through which the sun's rays can be focused on the hatches in question according to the need (Figure 79).

In addition, artificial, electrical lighting is /130
supplied by extracting current from the solar power plant.

Supplying Air and Heat

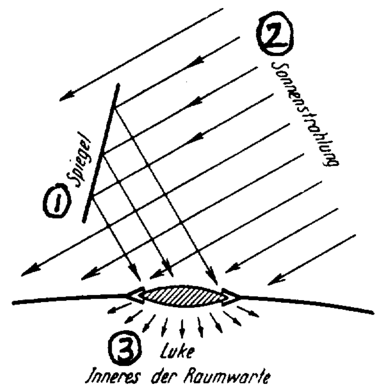


Figure 79. The mirror focuses the rays of the sun directly on the hatch.

Key: 1. Mirror; 2. Solar radiation; 3. Hatch/Interior of the space station.

Even heating the space station takes place by directly utilizing solar radiation, more specifically, according to the principle of heating air simultaneously with ventilation.

For this purpose, the entire air of the space station is continuously circulating among the rooms requiring it and to a ventilation system in which its cleaning, regeneration and heating occurs. A large, electrically driven ventilator provides for maintaining air movement. Pipelines necessary for this process are also available. They discharge through small screened openings (Figures 60 and 61, O) into the individual rooms where it is consumed. The ventilation system (Figure 80) is equipped similar to the air renewing device suggested by Oberth. Initially, air flows through a dust filter. Then it arrives in a pipe cooled by radiating into outer space; the temperature in this pipe is lowered gradually to below - 78° Celsius, thus separating the gaseous admixtures, and more specifically, first the water vapor and later the carbon dioxide. Then, the air flows through a heating pipe heated by means of the concentrated

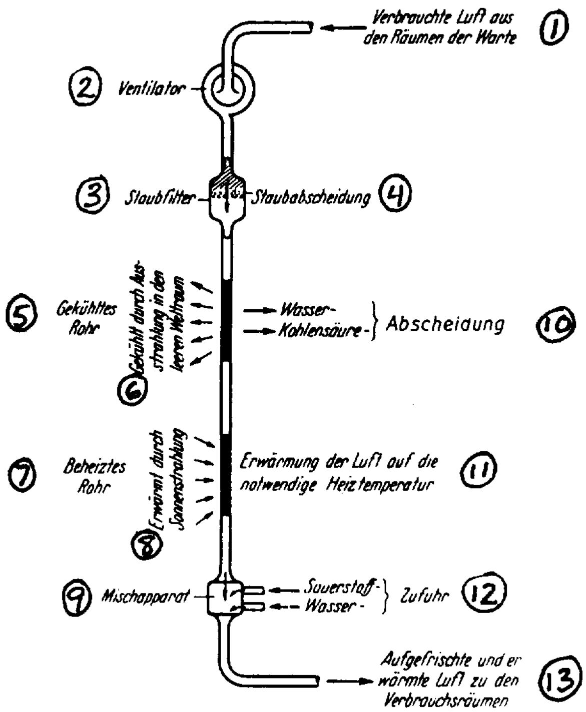


Figure 80. Schematic representation of a ventilation system. The cooled and heated pipes could be build, for example, similar to the ones shown in Figure 75, D and/or K. [TRANSLATOR'S NOTE: THE ORIGINAL SHOULD READ FIGURE 77.]

Key: 1. Stagnant air from the rooms of the space station; 2. Ventilator; 3. Dust filter; 4. Dust separation; 5. Cooled pipe; 6. Cooled by radiating into empty space; 7. Heated pipe; 8. Heated by solar radiation; 9. Mixer; 10. Water and carbon dioxide separation; 11. Heating the air to the required temperature; 12. Oxygen and water supply; 13. Regenerated and heated air to the rooms where it is consumed.

rays of the sun, thus bringing to the temperature necessary for maintaining the heat in the rooms. Finally, its oxygen and moisture contents are also supplemented to the proper extent, ultimately again flowing back into the rooms of the space station.

This process ensures that only the oxygen consumed by breathing must be replaced and consequently resupplied from the ground; the non-consumed components of the air (in particular, its entire nitrogen portion) remain continually in use. Since the external walls of the space station do not participate in the subsequent heating, it must be inhibited as much as possible that these walls dissipate heat into outer space through radiation; for this reason, the entire structure is highly polished on the outside.

## Water Supply

The available water supply must also be handled just as economically: all water used is collected and repeatedly made reusable through purification. For this purpose, large distillation equipment is used in which the evaporation and subsequent condensation of the water is accomplished in a similar fashion as was previously described for the solar power plant: in pipes heated by the concentrated rays of the sun (Figure 77, D) and cooled by radiating into outer space (Figure 77, K).

## Long Distance Communications

The equipment for long distance communication is very important. Communication takes place either through heliograph signaling using a flashing mirror, electrical lamps, spot lights, colored disks, etc., or it is accomplished electrically by radio or via wires within the most confined areas of the space station.

In communicating with the ground, communicating by /132
means of heliograph signaling has the disadvantage of being unreliable because its usage depends on the receiving station on the Earth being cloudless.

Therefore, the space station has at its disposal large radio equipment which makes possible both telegraph and telephone communications with the ground at any time. Overcoming a relatively significant distance as well as the shielding effect exerted by the atmosphere on radio waves (Haevesid layer), are successful in this regard (by selecting an appropriate direction of radiation) by using shorter, directed waves and sufficiently high transmission power, because conditions for this transmission are favorable since electric energy can be generated in any quantities by means of the solar power plant and because the construction of any type of antenna presents no serious problems as a result of the existing weightlessness.

## Means of Controlling the Space station

Finally, special oscillating motors and thrusters are planned which serve both to turn the space station in any direction and to influence its state of motion as necessary.

On the one hand, this option must exist to be able to maintain the space station in the desired orientation to the Earth and/or in the required position for directing the rays of the sun, because for this purpose, not only all those impulses of motion (originating from outside of the system!) must be continually compensated for, which are inevitably imparted to the space station again and again in the traffic with space ships, but the effect of the Earth's movement around the sun must also be continually taken into account.

On the other hand, this is also necessary in order to /133 enable the space station to satisfy its special tasks, which will be discussed later, because any changes of its position in space must be possible for performing many of these tasks and finally because the necessity can occasionally arise for performing location repositioning in relation to the Earth's surface.

The oscillating motors are standard direct current electrical motors with a maximum RPM as high as possible and a relatively large rotor mass. Special brakes make it possible rapidly to lower or shut off its operation at will.

They are installed in such a manner that their extended theoretical axis of rotation goes through the center of mass of the structure.

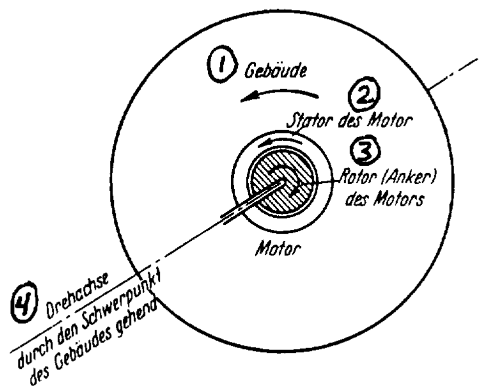


Figure 81. Operating characteristics of an oscillating motor (see the text).

Key: 1. Structure; 2. Stator of the motor; 3. Rotor (armature) of the motor; 4. Axis of rotation going through the center of mass of the structure.

Now, if an oscillating motor of this type is started (Figure 81), then its stator (the otherwise stationary part of the electrical motor) and consequently the entire structure firmly connected to the motor rotate simultaneously with its rotor (armature) around the axis of the motor – however, in the opposite direction and, corresponding to the larger mass, rotate much slower than /134 the rotor. More specifically, it rotates until the motor is again turned off, with the rapidity at which it functions varying depending on the RPM imparted to it. (In the present case, it is a matter of a "free system," in which only internal forces are active.) Since these motors are now oriented in such a fashion that their axes are perpendicular to one another like those of a right angle, three dimensional coordinate system (Figure 82), the structure can be swung in any manner due to their cooperative combined effects.

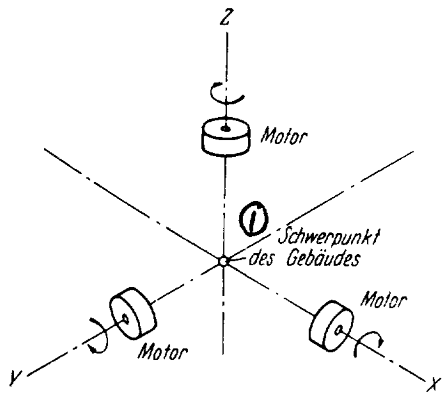


Figure 82. Orientation of the oscillating motors. The 3 axes are perpendicular to one another and go through the center of mass of the structure.

Key: 1. Center of mass of the structure.

The thrusters are similar both in construction and in operating characteristics to the propulsion equipment of the space ships described previously[28]. They are, however, much less powerful than those described, corresponding to the decreased demands imposed on them (the accelerations caused by them need not be large). They are positioned in such a manner that an acceleration can be imparted to the structure in any direction by using them.

## Partitioning the Space Station into 3 Entities

It would, no doubt, be conceivable to design technical equipment which make possible staying in empty space despite the absence of all materials; however, even the absence of gravity would (at least in a physical context, probably otherwise also) not form any critical obstacle to the

[28] See Pages 46 and 47.

the development of life, if the various peculiarities resulting from this condition are taken into consideration in the manner previously indicated.

However, since the weightless state would be associated in every case with considerable inconveniences and could even perhaps prove to be life-threatening over very long periods, artificially replacing gravity is provided for in the space station.

In accordance with our previous discussion, the force /135 of gravity, because it itself is an inertial force, can likewise only be influenced, offset or replaced by an inertial force, more specifically, by centrifugal force if a lasting (stabile) state is supposed to result. This force allows us to maintain the space station in its vertiginous altitude and to support it there to a certain degree. However, since the latter also leads at the same time to completely nullifying the gravitational state in the space station itself, the centrifugal force now is used again (however, in another manner as previously used) to create the missing gravitational state anew.

Strictly speaking, this is very easy to accomplish: only those parts of the structure, in which the centrifugal force and consequently a gravitational state are supposed to be produced, must be rotated in a correspondingly rapid fashion around their center of mass (center of gravity). At the same time, it is more difficult to satisfy the following requirement: the space traveller can exit and enter the structure, connect cables and attach large concave mirrors simply and safely when these parts of the structure are rotating. Another requirement is that it is also possible to reposition the entire structure not only taking the sun's rays into account, but also according to the respective demands of performing distant observations.

These conditions lead now to a partitioning of the space station into three individual entities: the "living wheel," in which a man-made gravitational state is continually maintained through rotation, thus having the same living conditions as exist on Earth, and which is normally used for relaxing and for living; the "observatory;" and finally the "machine room." While retaining the weightless state, the latter two are only furnished in accordance with their special functions; instead they provide the personnel on duty with a compartment for performing their work, however only for a short stay.

However, this partitioning of the space station makes it necessary to put into effect special procedures in order to compensate for the mutual attraction of the individual entities, because even though this is very slight due to the relative smallness of the attracting masses, the mutual attraction would nevertheless lead to a noticeable approach over a longer period (perhaps in weeks or months) and finally even to the individual entities of the space station impacting one another. The individual entities, therefore, must either: /136

be positioned as far as possible from one another (at several hundred or thousand meters distance), so that the force of mutual attraction is, if at all possible, low, thus permitting the approach which is occurring nonetheless to be compensated for over time by means of thrusters, or;

be as close as possible to one another and mutually braced in a suitable manner.

In this case, we decided on the first alternative (Figure 94).

As is generally known, both the velocity of rotation and the centrifugal force on the various points of a rotating object are proportional to the distance from its center of rotation, to the axis (Figure 83); i.e., the velocity is that much greater, the further the point in question is distant from the axis and that much less, the closer it is to the axis; it is equal to zero on the theoretical axis of rotation itself.

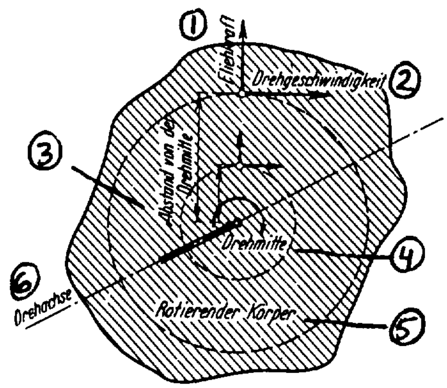


Figure 83. Velocity of rotation and centrifugal force on a rotating object.

Key: 1. Centrifugal force; 2. Velocity of rotation; 3. Distance from the center of rotation; 4. Center of rotation; 5. Rotating object; 6. Axis of rotation.

Accordingly, the rotating part of the space station must be structured in such a manner that its air lock and the cable connections in the center of the entire structure are in the axis of rotation because the least motion exists at that point, and that those parts, in which a gravitational effect is to be produced by centrifugal force, are distant from the axis on the perimeter because the centrifugal force is the strongest at that point.

These conditions are, however, best conformed to when /138
the structure is laid out in the shape of a large wheel as

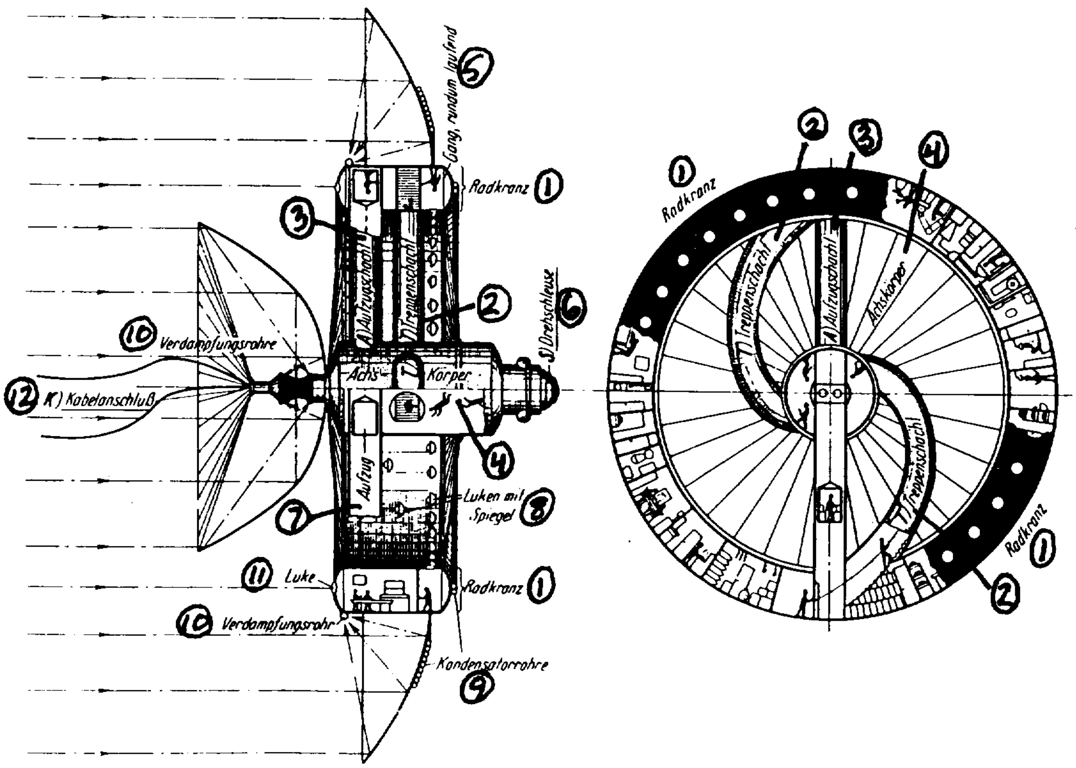

Figure 84. The Living Wheel. Left: Axial cross section. Right: View of the side constantly facing the sun, without a concave mirror, partially in sectional drawing.

Key: 1. Wheel rim; 2. Well of the staircase; 3. Elevator shaft; 4. Axle shaft; 5. Circular corridor; 6. Rotating air lock; 7. Elevator; 8. Hatches with mirrors; 9. Condenser pipes; 10. Evaporation tube; 11. Hatch; 12. Cable connection.

previously indicated (Figures 84, 89 and 90): the rim of the wheel is assembled out of cells and has the form of a ring braced by wire spokes towards the axis. Its interior is separated into individual rooms by partitions; all rooms are accessible from a wide enclosed corridor going around the entire structure. There are individual rooms, larger sleeping bays, work and study areas, mess hall, laboratory, workshop, dark room, etc., as well as the usual utility areas, such as a kitchen, bath room, wash room and similar areas. All rooms are furnished with modern day comforts; even cold and warm water lines are available. In general, the rooms are similar to those of a modern ship. They can easily be furnished just like on Earth because an almost normal, terrestrial gravitational state exists in these rooms.

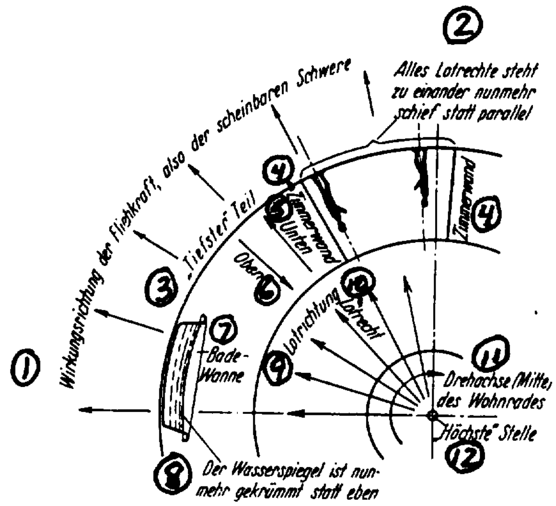

Figure 85. Directional relationships in the living wheel.

Key: 1. Directional effect of the centrifugal force, that is, of apparent gravity; 2. Everything vertical is from now on tilted instead of parallel; 3. "Lowest" part; 4. Partition; 5. Down; 6. Up; 7. Bathtub; 8. The water level is curved from now on instead of level; 9. Vertical direction; 10. Vertical; 11. Axis of rotation (center) of the living wheel; 12. "Highest" point.

However, to create this gravitational state, the entire structure for the case of a diameter of 30 meters, for example, must be rotated to such a manner that it performs a complete rotation in about 8 seconds, thus producing a centrifugal force in the rim of the wheel which is just as large as the gravitational force on the Earth's surface.

While the force of gravity functions towards the center, the centrifugal, on the other hand, is directed away from the center. Therefore, "vertical" in the living wheel /139 means the reverse as on Earth: the radial direction from the center (from the axis of rotation) directed outward (Figure 85). Accordingly, "down" now points towards the perimeter and at the same time to the "lowest" part, while "up" now points towards the axis and at the same time to the "highest" point of this man-made celestial body. Taking its smallness into account, the radial course of the vertical direction, which for the most part is not effective on the Earth due to its size, now clearly becomes evident in the celestial body. The consequence of this is that everything "vertical" (such as human beings standing erect, the partitions of the rooms, etc.) is now tilted instead of parallel to one another and everything "horizontal" (e.g., water surface of the bathtub) appears curved instead of flat (see Figure 85).

A further peculiarity is the fact that both the velocity of rotation and the centrifugal force, as a result of their decrease towards the center of rotation, are somewhat less at the head of a person standing in the living wheel than at his feet (by approximately 1/9 for a wheel diameter of 30 meters) (Figure 83). Of this, the difference of the centrifugal forces should hardly be noticeable, while that of the velocity of rotation should be noticeable to some degree, more specifically, when performing up and down (i.e., radially developing) movements, such as lifting a hand, sitting down, etc. /140

However, all of these phenomena make themselves felt that much less, the larger the diameter of the wheel is. In the previously selected case (30 meters in diameter), only a slight effect would be perceptible.

Since the equipment for connecting to the outside is installed in the region of the axis (because at that point the least motion exists!), the axial beam forms the "entrance hall" of the entire structure to some extent. The beam has a cylindrical shape. On both of its ends (around

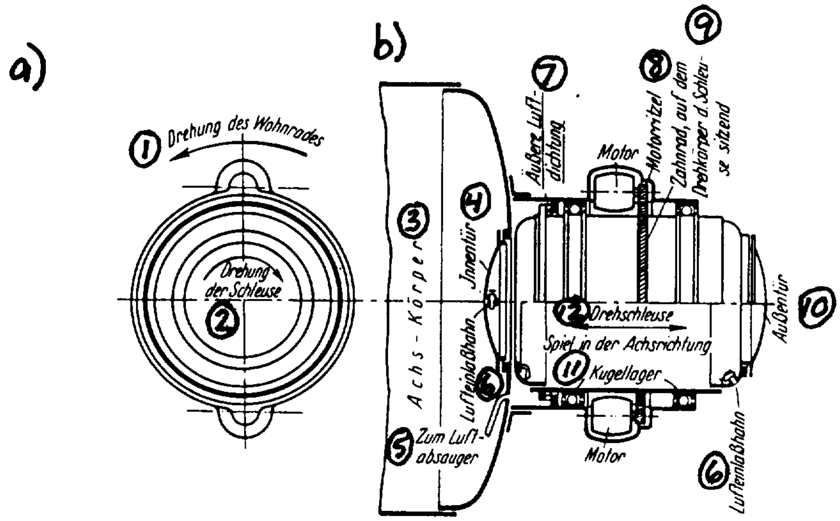


Figure 86. a) Top view onto the external door of the rotating air lock of the living wheel. b) Axial cross section through the rotating air lock of the living wheel. (See Figure 84 and the text.)

The ball bearings are designed in such a manner that they allow clearance in the direction of the axis through which closing and/or releasing is possible of the external air seal which connects the air lock airtight to the inside of the living wheel when the inside door is open.

Key: 1. Rotation of the living wheel; 2. Rotation of the air lock; 3. Axial beam; 4. Inside door; 5. To the air suction ventilator; 6. Air intake path; 7. External air seal; 8. Motor pinion gear; 9. Gear on the rotor of the lock; 10. Outside door; 11. Ball bearing; 12. Rotating air lock / Clearance in the axial direction.

those points where it is penetrated by the theoretical axis of rotation), the air lock is positioned on one side and the cable connection on the other side (Figure 84, S and K).

The air lock is made rotatable here in order to /141
to ease the transition between the rotational movement of the living wheel and the state of rest of outer space (Figure 86). When "outgoing," the air lock is stationary vis-a-vis the living wheel (it is rotating vis-a-vis outer space). Persons can, therefore, move easily out of the living wheel into the air lock. Now, the latter is slowly

started by electrical power – more specifically, opposite to the direction of rotation of the living wheel – until it reaches the same number of revolutions as the living wheel. As a result, the air lock is stationary in relation to outer space and can now be departed just as if the living wheel was not even rotating. The process is reversed for "incoming."

With some training, starting the air lock can, however, be dispensed with because the living wheel rotates only relatively slowly at any rate (one complete revolution in approximately 8 seconds in the previously assumed case with a 30 meter diameter of the wheel).

Even the cable connection to the other side of the axle beam is designed in a basically similar manner in order to prevent the cable from becoming twisted by the rotation of the living wheel. For this reason, the cable extends out from the end of a shaft (Figure 87), which is positioned on the theoretical axis of rotation of the living wheel and is continually driven by means of an electrical motor in such a manner that it rotates at exactly the same number of revolutions as the living wheel – but in reverse like the wheel. As a result, the shaft is continually stationary in relation to outer space. The cable extending from the shaft cannot, in fact, be damaged by the rotation of the living wheel.

Stairs and electrical elevators installed in their own /142
tubular shafts connect between the axial beam and rim of the wheel. These shafts run "vertically" for the elevators, i.e., radially (Figure 84, A). On the other hand for the stairs, which must be inclined, the shafts are – taking the divergence of the vertical direction into account – curved to logarithmic spirals which, however, gradually become steeper towards "up" (towards the center) (Figures 88 and 84, T) according to the gravitational effect (centrifugal force) which is decreasing more and more towards that point.

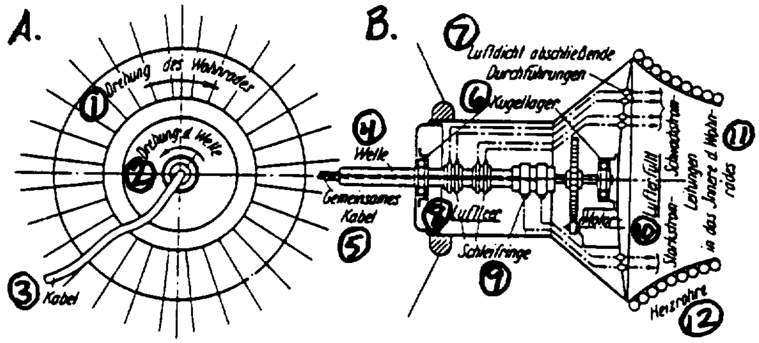


Figure 87. A. Top view onto the cable connection of the living wheel. B. Axial cross section through the cable connection of the living wheel.
(See Figures 84, K, and the text.)

Key: 1. Rotation of the living wheel; 2. Rotation of the shaft; 3. Cable; 4. Shaft; 5. Common cable; 6. Ball bearings; 7. Passage ways sealed airtight; 8. Airless; 9. Sliding contact rings; 10. Air filled; 11. High and low voltage current lines on the inside of the living wheel; 12. Heat tube.

By using the stairs and/or elevators in an appropriately slow manner, the transition can be performed gradually and arbitrarily between the gravitational state existing in the rim of the wheel and the absence of gravity in outer space.

Supplying the living wheel with light, heat, air and /144
water takes place in the fashion previously specified in general for the space station: by employing the engineering equipment described there. The only difference being that the wall of the wheel rim always facing the sun also acts to heat the living wheel[29]; for this reason, this wall is colored matte black (Figures 89 and 84), in contrast to the otherwise completely highly polished external surfaces of the structure. A small solar power plant sufficient for

[29] Naturally, the sun's help could quickly be dispensed with and supplying the heat of the living wheel could also be provided solely by means of air heating. The entire rim of the wheel would then have to be highly polished.

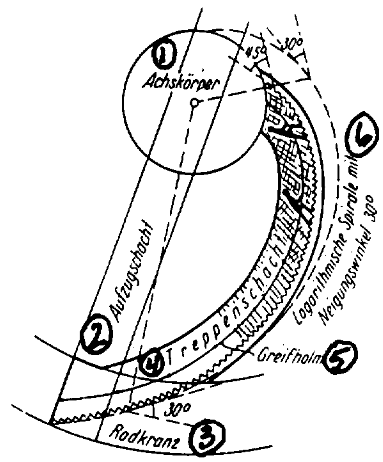


Figure 88. Well of the living wheel staircase.

Key: 1. Axial beam; 2. Elevator shaft; 3. Rim of the wheel; 4. Well of the staircase; 5. Railing; 6. Logarithmic spiral with a slope of 30°.

emergency needs of the living wheel is also available.

All storage rooms and tanks for the consistently adequate supplies of air, water, food and other materials, as well as all mechanical equipment are in the wheel rim. The concave mirrors associated with these equipment and the matte black colored steam generator and condenser pipes are attached to the living wheel on the outside in an appropriate manner and are rotating with the living wheel (Figures 84, 89 and 90).

Finally, oscillating motors and thrusters are planned which, besides the purposes previously indicated, can also generate the rotational motion of the living wheel and halt it again, and/or influence this motion in a controlling sense.

## The Observatory and Machine Room

The critical idea for the living room for creating living conditions as comfortable as possible must be of

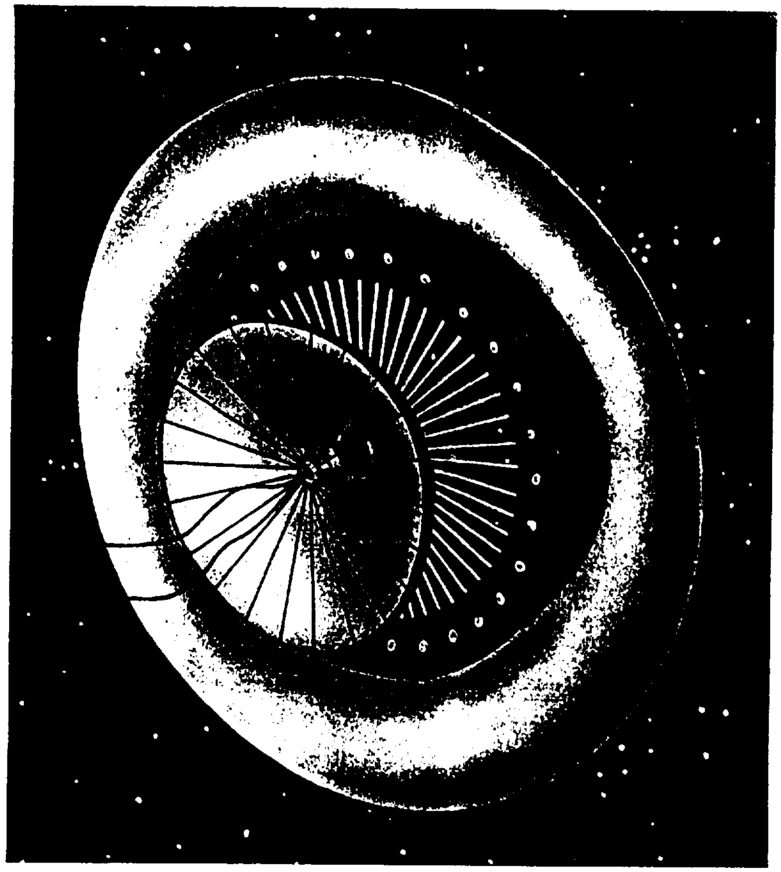

Figure 89. Total view of the side of the living wheel facing the sun. The center concave mirror could be done away with and replaced by appropriately enlarging the external mirror.

secondary importance for the observatory and machine room compared to that requirement for primarily making these entities suitable for satisfying their special tasks. For this reason, eliminating the weightless state is not accomplished, as noted previously, for these entities.

Primarily, it is important for the observatory (Figure 91) that any arbitrary position in space, which is necessitated by the observations to be carried out, can easily be assigned to it. It must, therefore, be completely /145 independent of the sun's position; that is, it may not have any of the previously described equipment which are powered

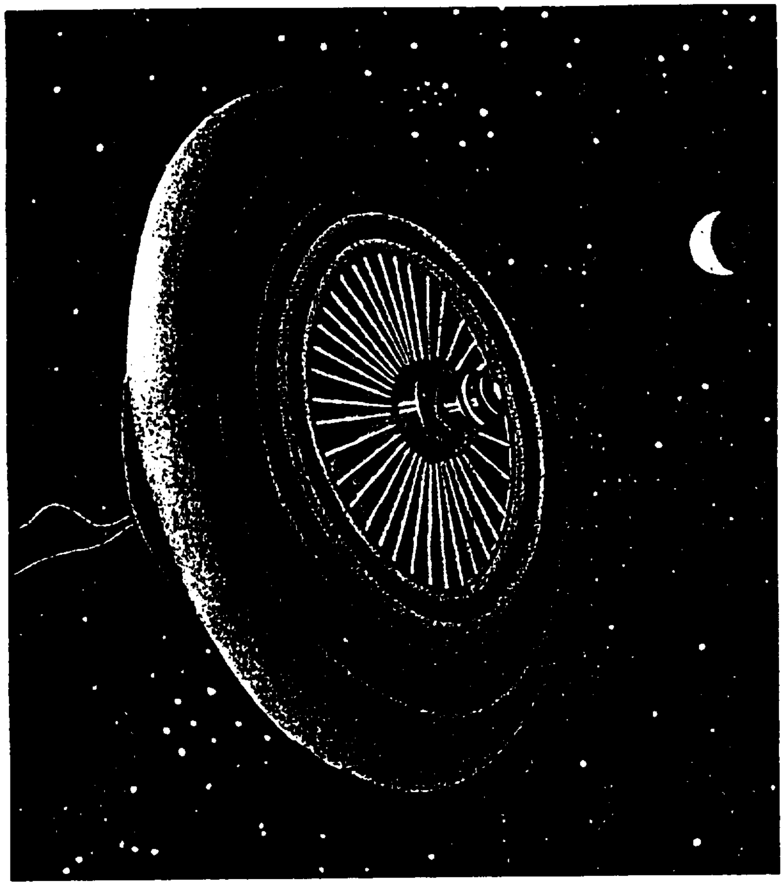

Figure 90. Total view of the dark side of the living wheel.

by the sun's rays. For this reason, ventilation and the simultaneous heating of the observatory as well as its electrical supply take place from the machine room; consequently, both entities are connected on the outside through a flexible tube or by means of a cable (Figures 91 and 92). Nevertheless, a precaution is taken to ensure that the ventilation of the structure can also be carried out automatically in an emergency by employing purification cartridges, as is customary in modern day diving suits.

The following are present in the observatory: for the most part, long-distance observation equipment in accordance with the indented purpose of this entity and, furthermore, all controls to be activated as a function of the long-

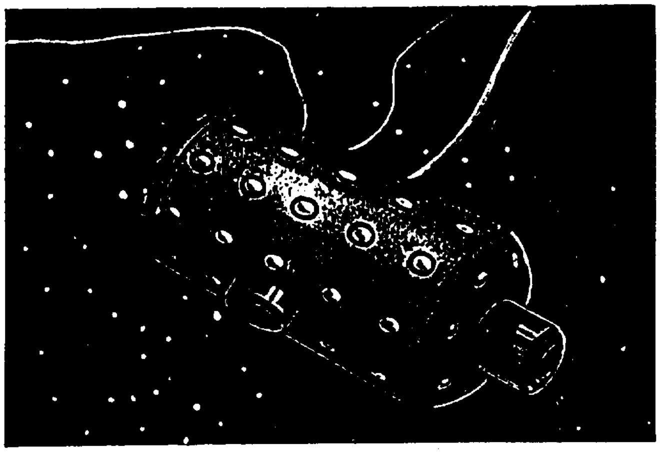

Figure 91. An example of the design of an observatory. Taking into account the overpressure of 1 atm. existing within it, the observatory almost has the shape of a boiler. The air lock, two electrical cables (left), the flexible air tube (right) and the lighting hatches can be seen.

distance observation, such as those of the space reflector (see the following). Finally, a laboratory for performing experiments in the weightless state is also located in the observatory.

The machine room is designed for housing the more /146 important mechanical systems common to the entire space station, in particular those which serve for the large-scale utilization of the sun's rays. For the most part, it contains, therefore, the main solar power plant including storage batteries. Furthermore, the entire equipment of the large transmission station are stored here and finally a ventilation system is present, which simultaneously functions for the observatory.

Supplying solar energy takes place through a powerful concave mirror firmly connected to the structure (Figure 93), in whose focal point the evaporating and heating pipes are located, while the condenser and cooling pipes are attached to its back side.

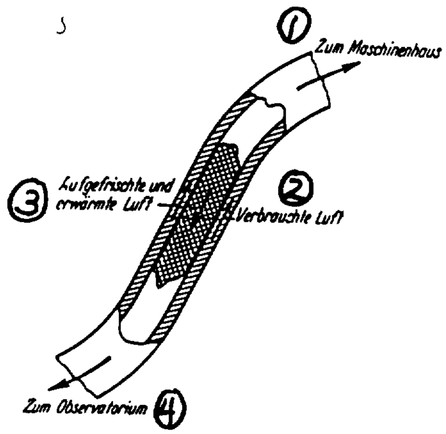


Figure 92. The flexible tube for connecting the observatory with the ventilation system in the machine room.

Key: 1. To the machine room; 2. Spent air; 3. Refreshed and heated air; 4. To the observatory.

The position of the machine room is, therefore, determined beforehand: it must always be maintained in such a fashion that the concave mirror completely absorbs the sun's rays with its front side.

Lighting of both the observatory and machine room takes place in the manner already described in general terms for the space station. All external surfaces of the structure are keep highly polished for reducing the cooling down effect. Finally, both entities are also equipped with oscillating motors and thrusters.

Kitchens, water purification systems, washing /147
facilities, and similar units are missing, however, taking into account the very troublesome maintenance of liquids in the weightless state. The living wheel is available for eating and personal hygiene. The necessities of food and drink in the observatory and machine room must be brought in from the living wheel, already prepared in the manner compatible with the weightless state.

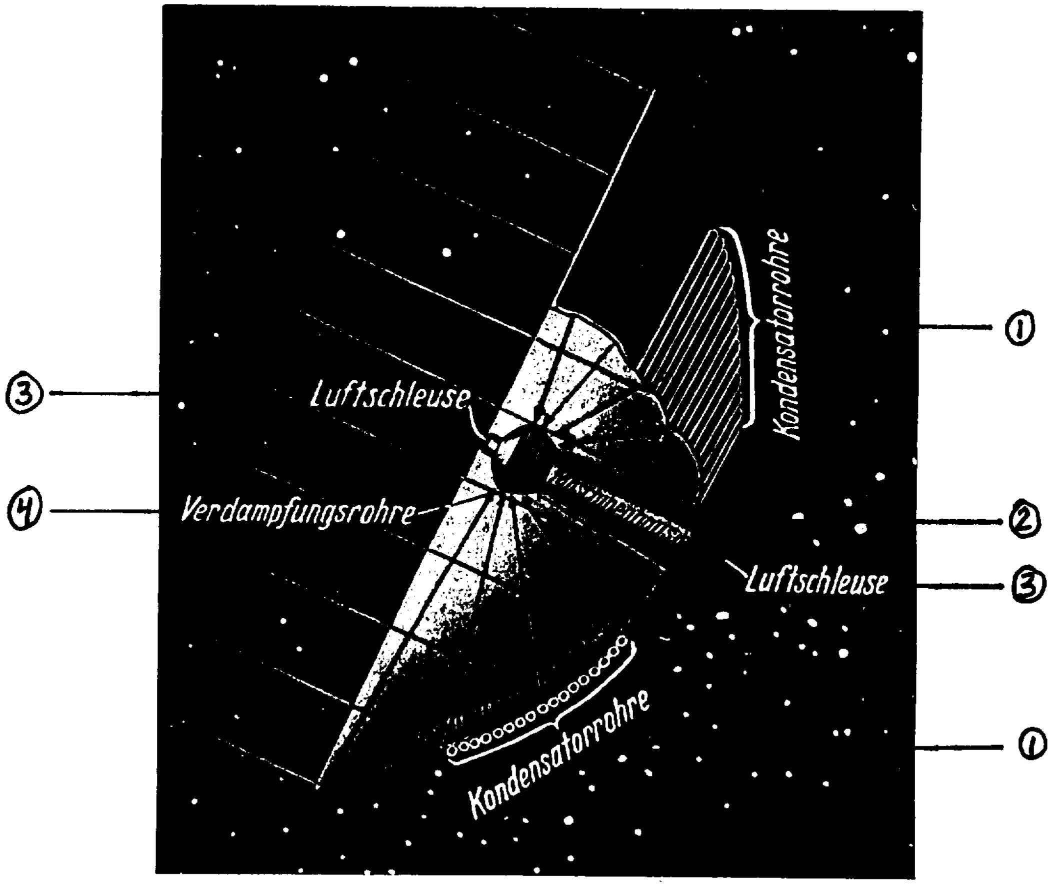


Figure 93. Example of the design of the machine room shown in the axial cross section.

Key: 1. Condenser pipes; 2. Machine room; 3. Air lock; 4. Evaporating pipes.

## Providing for Long-Distance Communications and Safety

Communicating among the individual entities of the space station takes place in the manner previously indicated either through signalling with lights or by means of radio or finally by using wires. Accordingly, all three entities are equipped with their own local radio stations and, furthermore, are connected to one another by cables which simultaneously carry the high voltage current.

Finally, each one of the three entities are furnished with reserve supplies of food, oxygen, water, heating material and electricity (stored in reserve batteries) in such a manner that it can house the entire crew of the space station for some time in an emergency, if, for instance, both other entities should become unusable at the same time through an accident. In this manner, the tri-partitioning of the space station designed for engineering reasons also contributes considerably to safety. In order to enhance the latter still further, a precaution is taken to ensure that each entity cannot only be in communication with the ground from the central radio station, but independently via its own flashing mirror system.

## Partitioning the Space station into 2 Entities

Instead of 3 parts, the space station could, however, even be partitioned into only 2 entities, more specifically, by combining the living room and machine room. Basically, this would be possible because the position in outer space for these two entities is determined only by the direction of the sun's rays, and more specifically, determined in the same manner.

In this regard, if the mirror of the machine room is to be prevented from completely participating in the relatively (for its size) rapid rotation of the living wheel, then by way of example the living wheel and machine room (including its mirror) could both be rotated around a common axis of rotation — but in a reverse sense. Or the living wheel and /149 machine room could be completely fused together into one structure and the large mirror of the machine room rotated solely around its axis of rotation, likewise in an opposite direction. Other methods could also be employed.

The advantages from the above would be as follows:

1. Movement within the space station is simplified.

2. The procedures necessary in a separated partitioning which compensates for the mutual attraction of the entities, are eliminated between living room and machine room.

3. The rotational motion of the living wheel can now be produced, changed and stopped through motor power instead of otherwise by means of a thruster – without any expenditure of fuel –, because now the entire machine room and/or its large mirror are available as a "counter mass" for this purpose (consequently, the reverse rotational direction of the mirror).

These advantages are faced with the disadvantage that design difficulties result which are not insignificant, yet are resolvable. We want to refrain from examining any further this positioning of the space station in more detail here in order not to complicate the picture obtained of it up to this point.

## The Space Suit

Both for assembling and operating the space station (moving between individual entities, interfacing with the space ships, performing varying tasks, etc.) it is necessary to be able to remain outside of the enclosed rooms in the open. Since this is only possible using the previously referenced space suits, we have to address these suits in more detail.

As previously explained, they are similar to the modern diving and/or gas protective suits. As is the case with the other two suits, the space suit garment must not only be airtight, resistant to external influences and built in such a manner that it allows movement to be as unrestrictive as possible, but additionally for space suits, it must have a large tensile strength because a gas pressure (overpressure /150
of the air in relation to empty space) of one whole atmosphere exits within the garment. And moreover, it should be insensitive to the extremely low temperatures resulting in empty space due to radiation. The garment may neither become brittle nor otherwise sacrifice strength.

Without a doubt, fairly significant requirements are imposed on the material of the garment of such a space suit.

In any case, the issue of protecting against cold presents the most difficulty; that is, more correctly stated, the task of maintaining the loss of heat through radiation within acceptable limits. Attention must, therefore, be given to restricting the capability of the garment to radiate to a minimal degree. The best way of attaining this goal would be to make the suit in its entirety highly polished on the outside. It would then have to be made either completely of metal or at least coated with a metal. However, an appropriately prepared flexible material insensitive to a strong cooling down effect would perhaps suffice as a garment, if it is colored bright white on the outside and is as smooth as possible.

Nevertheless, the advantage of a material of this nature may not be all that great as far as the freedom of movement is concerned, because even when the garment used is flexible, it would be stiff – since the suit is inflated (taut) as a result of the internal overpressure –, such that special precautions would nevertheless have to be taken for achieving sufficient movement, as if the garment was made of a solid material, such as metal, in the first place. The all-metal construction probably would appear to be the most compatible because numerous experiences from the modern day armor diving suits are available regarding the method of designing such stiff suits and because a structure similar perhaps to flexible metal tubes could partially be given to them.

We will, therefore, assume that the space suits are designed in this manner. As a result of a completely external highly polished surface, their cooling down is prevented as much as possible due to thermal radiation. /151
Additionally, a special lining of the entire suit provides for extensive thermal insolation. Nevertheless, in case

cooling down is felt during a long stay on the outside, it is counteracted by radiation by means of mirrors as a result of the irradiation of the side of the space suit in the sun's shadow.

Supplying air takes place similarly to modern day deep sea divers. The necessary oxygen bottles and air purification cartridges are in a metal knapsack on the back.

Since voice communication through airless space is possible only via telephones and since a connection via wires would be impractical for this purpose, the space suits are equipped with radio communication gear: a small tubular device functioning as sender and receiver and powered by accumulators is also stored in the knapsack for this purpose. The microphone and the head phone are built firmly into the helmet. A suitably installed wire and/or the metal of the suit serves as an antenna. Since each individual entity of the space station is equipped for local radio communication, the humans suspended in the open can, therefore, speak both with each other and with the interior of the space station, just like in the air-filled space – however, not by means of air waves, but through ether waves.

For special safety against the previously described danger of "floating away into outer space" threatened during a stay in the open, the local radio stations are, moreover, equipped with very sensitive alarm devices which activate, even at great distances, in response to possible calls for help from the space suits.

In order to prevent mutual interference, various wavelengths are defined naturally for the individual types of local radio communications; these wavelengths can be adjusted in a simple manner at the radio devices in the space suits. Small hand-held thrusters make possible random movement. Their fuel tanks are also located in the knapsack along with the previously described devices.

The traffic between the Earth and the space station takes place through rocket-powered space ships, like those described in general in the first part of this book. It may complete the picture to experience such a trip at least in broad outlines:

The space ship is readied on the Earth. We enter the control room, a small chamber in the interior of the fuselage where the pilot and passengers stay. The door is locked airtight from the inside. We must lay down in hammocks.

Several control actions by the pilot, a slight quaking of the vehicle and in the next moment we feel as heavy as lead, almost painfully the cords of the hammocks are pressed into the body, breathing is labored, lifting an arm is a test of strength: the ascent has begun. The propulsion system functions and lifts us up at an acceleration of 30 $m/sec^2$, causing us to feel an increase in our weight four times its normal value. It would have been impossible to remain standing under this load.

It does not take long – because the increased heavy feeling stops for a moment, only to start up again immediately. The pilot explains that he has just jettisoned the first subrocket which is now spent, and started the second one.

Soon, new controlling actions are taking place: as explained by the pilot, we have already attained the necessary highest climbing velocity; for this reason, the vehicle was rotated by 90°, allowing the propulsion system to operate now in a horizontal direction in order to bring us to the necessary orbital velocity.

We have already attained this velocity. Only several /153
minutes have elapsed since launch; however, it seem endless to us, having to put up with the strenuous state of elevated

gravity. The pressure on us is gradually diminishing. First we feel a pleasant relief; then, however, – an unjustified oppressive fear: we believe we are falling, crashing into the depths. The valiant pilot attempts to calm us: he has slowly turned the propulsion system off. Our motion takes place now only by virtue of our own kinetic force, and that which was felt as a fall is nothing other than the feeling of weightlessness, something which we must get used to for good or for bad. Easier said then done; but since no other possibility exists, even this was finally successful.

In the meantime, the pilot has acutely observed with his instruments and referenced his tables and travel curves. Several times the propulsion system was restarted for a short time: small orbital corrections had to be made.

Now the destination is reached. We put on space suits, the air is vented from the control room, the door is opened. Ahead of us at some distance we see something strange, glittering in the pure sunlight like medallions, standing out starkly from the deep black, star-filled eternal night: the space station (Figure 94).

Nevertheless, we have little time to marvel. Our pilot pushes away and floats toward the space station. We follow him, but not with very comfortable feelings: an abyss of almost 36,000 km gapes to the Earth!

For the return trip, we discover our vehicle equipped with wings. These are carried on board in a dismantled condition during the ascent and have now been attached, a job presenting no difficulties due to the existing weightlessness.

We re-entered the control room of the space ship; the door is closed, air let in. At first the propulsion system begins to function very slowly: a slight heavy feeling appears. We must again lay down in the hammocks. Then, little by little the other thrusters are switched on by the

Figure 94. The entire space station with its 3 entities, seen through the door of a space ship. In the background — 35,900 km distant — is the Earth. The center of its circumferential circle is any point of the Earth's surface on the equator over which the space station continually remains suspended (see Pages /98 and /99). As assumed in this case, the space station is on the meridian of Berlin, more specifically, approximately on the southern tip of Cameroon.

pilot, causing the sensation of gravity to increase to /154
greater and greater strengths. We feel it this time to be even heavier than before, after we have become unaccustomed to gravity over short periods. The propulsion system now operates at full force, and more specifically, in a horizontal direction, yet in the opposite direction than

before, our orbital velocity and consequently the centrifugal force, which had carried us during the stay in the space station, must be decreased significantly to such a degree that we are freely falling in an elliptical orbit towards the Earth. A weightless state exists again during this part of the return trip.

In the meantime, we have come considerably closer to the Earth. Gradually, we are now entering into its atmosphere. Already, the air drag makes itself felt. The most difficult part of this trip is beginning: the landing. Now by means of air drag, we have to brake our travel velocity gradually, which has risen during our fall to Earth up to around 12 times the value of the velocity of a projectile, to such an extent that no overheating occurs during the landing as a result of atmospheric friction.

As a precautionary measure, we have all buckled up. The pilot is very busy controlling the wings and parachutes, determining the specific position of the vehicle, measuring the air pressure and outside temperature, and performing other activities. For several hours, we orbit our planet at breakneck speed: in the beginning, it is a head-down flight at an altitude of approximately 75 km; later, with a continual decrease of the velocity, we approach the Earth more and more in a long spiral and, as a result, arrive in deeper, denser layers of air; gradually, the terrestrial feeling of gravity appears again, and our flight transitions into a standard glided flight. As in a breakneck race, the Earth's surface rushes underneath us: in only half hours, entire oceans are flown over, continents transversed.

Nevertheless, the flight becomes slower and slower and we come closer to the ground, finally splashing down into the sea near a harbor.

And now to the important question: What benefits could the described space station bring mankind! Oberth has specified all kinds of interesting proposals in this regard and they are referenced many times in the following.

By way of example, special physical and chemical experiments could be conducted needing large, completely airless spaces or requiring the absence of gravity which, for that reason, cannot be performed under terrestrial conditions.

Furthermore, it would be possible to generate extremely low temperatures not only in a simpler fashion than on the Earth, but absolute zero could also be approached much closer than has been successful in our refrigeration laboratories (to date, approximately 1° absolute, that is, -272° Celsius, has been attained in these labs). Then, besides the method of helium liquefaction already in use for this purpose, the possibility of a very extensive cooling down by radiating into empty space would be available in the space station.

The behavior of objects could be tested in the condition of an almost complete absence of heat, something which could lead to extremely valuable conclusions about the structure of matter as well as about the nature of electricity and heat, as the experiments of that type carried out previously in our refrigeration laboratories would lead us to expect. Probably even practical benefits – perhaps even to the grandest extent – would also result as a further consequence of these experiments. The problem, for example, is also connected with discovering a method for utilizing the enormous amounts of energy bound up in matter.

Finally taking the special potentials offered by a space station into consideration, the question of polar light could lead to a final clarification of certain cosmic rays and many other natural phenomena not yet fully explained.

## Telescopes of Enormous Size

/157

As has been previously explained, due to the absence of an atmosphere no optical barrier exists in empty space standing in the way of using long range visibility instruments of significant sizes. However, from a construction point of view, conditions are very favorable for instruments of this type due to the existing weightlessness. The electrical power necessary for positioning the instruments and/or their components remotely is also available in the space station.

Thus for example, it would be possible in a simple fashion to maintain even kilometer-long reflecting telescopes by the fact that an electrically adjustable, parabolic mirror is positioned suspended correspondingly far from the observer in empty space. This type of instrument and similar long range visibility devices would be tremendously superior to the best ones available today on Earth. Without a doubt, it can be stated that almost no limits would exist at all for the efficiency of these instruments and consequently for the possibilities of long distance observation.

## Observing and Researching the Earth's Surface

Everything even down to the smallest detail on the Earth's surface would be detected from the space station using such powerful telescopes. Thus, we could perceive predetermined optical signals from the Earth by the most basic means and as a result keep research expeditions in communication with their home country and/or continually follow their fate. We could also scan unexplored lands, determining the make up of their soil, obtaining general information about their inhabitation and accessibility and as a result accomplishing valuable preliminary work for planned research expeditions, even making available to these expeditions detailed photographic mappings of the new destination lands.

Referencing this effort, it has already been indicated that cartography would be placed on an entirely new foundation, because by employing long range photography from the space station not only entire countries and even /158 continents could be mapped overall in the most basic fashion, but also detailed maps of any scale could be produced which would not be surpassed on accuracy even by the most conscientious work of surveyors and map makers. Land surveys of this type would otherwise have taken many years and required significant funding. The only task remaining then for map makers would be to insert the elevation data at a later date. Without much effort, very accurate maps can be obtained of all regions of the Earth still fairly unfamiliar, such as the interior of Africa, Tibet, North Siberia, the polar regions, etc.

Furthermore, important marine routes – at least during the day and as far as permitted by the cloud cover – could be kept under surveillance in order to be able to warn ships in time of dangers, such as floating icebergs, approaching storms and similar events, or to report ship accidents immediately.

Since the movement of clouds on more than one-third of the entire Earth's surface could be surveyed at one time from the space station and at the same time cosmic observations not possible from the Earth could be performed, an entirely new basis should also result for weather forecasting.

And not the least is to point out the strategic value of the possibilities of such long range observations: as a war plan unfolds, the entire deployment and battle area would open up before the eyes of the observer in the space station! Even while avoiding every movement during the day to the most extensive degree, the enemy would hardly be successful in hiding his intentions from such "Argus eyes."

## Researching the Stars

In an astronomical sense, the most splendid views open up for long distance observation from the space station because in this case, besides the possibility of being able to use large telescopes at will, two other advantages exist: the rays of the stars arrive completely unweakened and undistorted and the sky appears totally black.

Thus by way of example, the latter condition would /159
permit carrying out all those observations of the sun, which can be performed on the Earth only during a total eclipse of the sun, by simply dimming the solar disk using a round black screen.

Our entire solar system including all its planets, planetoids, comets, large and small moons, etc. could be studied down to the smallest detail. Even both ("lower") changing stars, Venus and Mercury, which are closer to the sun could be observed just as well as the more distant ("upper") planets, observations which are not possible from the Earth due to night effects, a subject already discussed. Therefore, the surfaces at least of all the neighboring stars (moon, Venus, Mars, Mercury) as far as they are visible to us could be precisely studied and topographically mapped by means of long distance photography. Yes, even the questions of whether the planets are populated or whether they were livable could probably be finally decided in this manner.

The most interesting discoveries would, however, presumably be in the fixed stars. Many unsolved puzzles of these extreme distances would be clarified and our knowledge of how the world came into being would be considerably enhanced perhaps by the fact that it would then be possible to infer with complete certainty the past and future fate of our own solar system and of the Earth.

Besides their usual value, all of these research results would also have, however, the greatest significance for the subsequent design of space ship travel, because if the conditions in those regions of space and on the celestial bodies to which our trip applies are exactly known to us, then a trip to outer space would no longer travel into the unknown and then could lose some of its danger.

## A Giant Floating Mirror /160

The potentials of a space station are by no means exhausted with the above descriptions. Based on the condition that as far as the space station is concerned the sun appears to be both unlimited and continuous (ignoring possible brief passes through the Earth's shadow), benefits could be derived, furthermore, for some engineering purposes on Earth. From the space station, the sun's rays – even on a large scale – could be artificially focused on various regions of the Earth's surface if, as Oberth suggests, giant mirrors were erected which were appropriately built and which orbited the Earth in a free orbit and hence were suspended over it.

According to Oberth, these mirrors should consist of individual bevels which are moveable in such a manner that any arbitrary position in the plane of the entire mirror can be remotely assigned to them through an electrical signal. By appropriately adjusting the bevels, it would then be possible, depending on the need, to spread the entire solar energy reflected by the mirror over wide regions of the Earth's surface or to concentrate it on single points of the Earth's surface or finally to radiate it into outer space if not being used.

The condition that "space mirrors" of this type would be in a weightless state as a result of their orbital motion, would considerably simplify their manufacture. According to Oberth, a circular network of wires could serve as a frame for their construction and, to this end, could be extended in space through rotation. The individual bevels would be located in its mesh and would consist of paper-thin sodium foils. According to Oberth's data, a mirror of this type with a diameter of 100 km would cost around 3 billion marks and require approximately 15 years for its completion.

Besides the above, there would, no doubt, be still other possibilities of constructing a large floating mirror of this type. At smaller diameters of perhaps only several 100 meters, we could certainly succeed in giving the entire /161
mirror such a rigid structure that it could be rotated at will around its center of mass, even in its entirety, by means of oscillating motors and that arbitrary positional changes could be performed with it.

The electrical energy necessary for controlling mirrors of this type would be available in the space station in sufficient quantities. The controls themselves would have to be placed in the observatory and positioned in such a fashion that they could be operated at the same time while performing observations by means of a giant telescope, making it possible to adjust the mirrors' field of light precisely on the Earth.

The uses of this system would be numerous. Thus, important harbors or airports, large train stations, even entire cities, etc. could be illuminated during the night with natural sunlight, cloud cover permitting. Imagine the amount of coal saved if, by way of example, Berlin and other cosmopolitan centers were supplied with light in this fashion!

Using very large space mirrors, it would, however, be possible, according to Oberth, to make wide land masses of the North inhabitable through artificial solar radiation, to keep the sea lanes to Northern Siberian harbors, to Spitzbergen, etc. free of ice, or to influence even the weather by preventing sudden drops in temperature and pressure, frosts, hail storms, and to provide many other benefits.

## The Most Dreadful Weapon

However, like any other technical achievement this could also be employed for combat purposes and, additionally, this would be a most horrible weapon, far surpassing all previous ones.

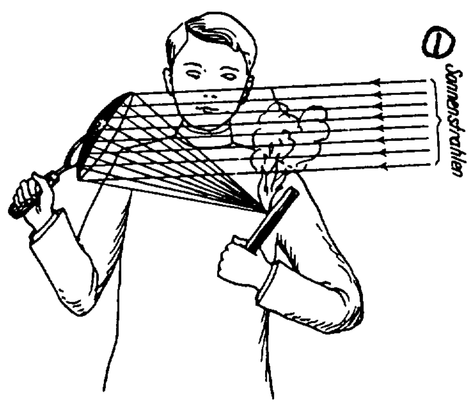


Figure 95. Igniting a piece of wood using a concave mirror. Key: 1. Sun's rays.

It is well known that fairly significant temperatures can be generated by concentrating the sun's rays using a concave mirror (in a manner similar to using a so-called "burning glass"). Even when a mirror is only the size of the human hand, it is possible to ignite a hand-held piece of paper or even wood shavings very simply in its focus (Figure 95).

Imagine that the diameter of a mirror of this type is not only 10 cm, but rather several 100 or even 1,000 of meters, as would be the case for a space mirror. Then, even steel would have to melt and nonflammable materials would hardly be able to withstand the heat over longer periods of time, if they were struck by solar light of such an enormous concentration. /162

And additionally if we now visualize that the observer in the space station using his powerful telescope saw the entire combat area spread out before him like a giant plan showing even the smallest details, including the base and the enemy's hinterland with all his land and sea routes, then we can envision just exactly what a manually controlled space mirror of this type would connote as a weapon.

It would be easy to detonate the enemy's munitions dumps, to ignite his war material storage area, to convert cannons, tank turrets, iron bridges, the tracks of important train stations, and similar metal resources into molten metal. Moving trains, important war factories, entire industrial areas and large cities could be set ablaze. Marching troops or ones in camp would simply be charred when the beams of this concentrated solar light were passed over them. And nothing would be able to protect the enemy's ships from being destroyed or burned out, like bugs are exterminated in their hiding place with a flame thrower, regardless of how powerful the ships may be and no matter whether they sought refuge in the strongest sea fortifications.

They would really be deadly rays! And yet they are none other that those life-giving ones which we welcome everyday from the sun; only a little "too much of a good thing." /163

Yet, it would never come to all of these horrible things, because a power would hardly dare to start a war with a country which controls weapons of this dreadful nature.

## To Alien Celestial Bodies

In previous considerations, we did not leave the confines of the overwhelming force of the Earth's attraction — its "territory in outer space," so to speak. What about the real goal of space flight: completely separating from the Earth and reaching alien celestial bodies?

Before examining this subject, a brief picture of the stars is provided as seen as a future destination from the standpoint of space ship travel. In the first place, we must broaden the scope of our usual notions, because if we want to consider the entire universe as our world, then the Earth, which previously appeared to us as the world, now becomes just our "confined native land." Not the Earth by itself! But everything that it holds captive by virtue of its gravitational force, like the future space station, yes even the moon must still be considered a part of our confined native land in the universe, a part of the "Earth's empire." How insignificant is the approximate 380,000 km distance of the moon to the Earth in comparison to the other distances in outer space! It is only a thousandth of the distance to the stars Venus and Mars located next to us after the moon, and even the Earth together with the entire moon's orbit could easily fit into the sun's sphere.

The next larger entity in the universe for us is the /164 solar system, with all its various, associated stars. These are the 8 large planets or changing stars, one of which is our Earth, (Figures 96 and 97) and numerous other celestial bodies of considerably smaller masses: planetoids, periodic comets, meteor showers, etc. Of the planets, Mercury is closest to the sun, followed by Venus, the Earth, Mars, Jupiter, Saturn, Uranus and Neptune, the most distant. Together with the moon, Venus and Mars are the stars directly adjacent to the Earth.

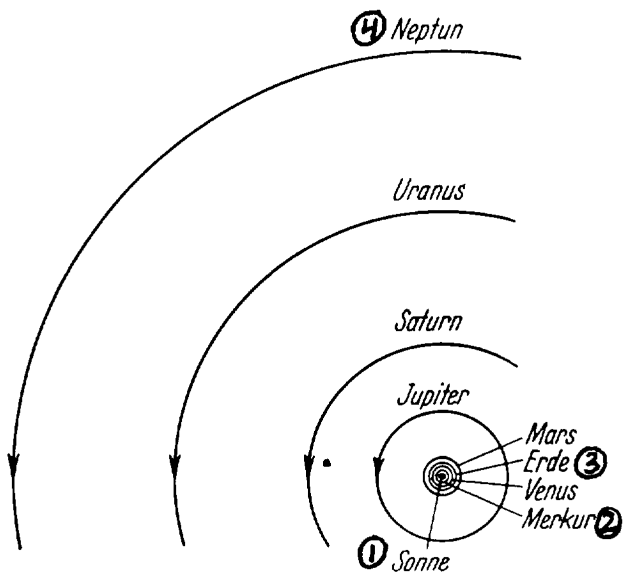


Figure 96. A sketch of the orbits of the 8 planets of our solar system in their mutually relative sizes.

Key: 1. Sun; 2. Mercury; 3. Earth; 4. Neptune.

All of these celestial bodies are continuously held captive to the sun by the effect of gravity; the bodies are continually forced to orbit the sun – as the central body – in elliptical orbits. The planets together with the sun form the "sun's empire of fixed stars," so to speak. They form an island in the emptiness and darkness of infinite space, illuminated by the sun's brilliance and heated and controlled at the same time by the unshakable power of the sun's gravitational force, and are thus linked in an eternal community. That island is our "extended native land" within the universe. An empire of truly enormous size: even light needs more than 8 hours to traverse it and it is racing through space at a velocity of 300,000 km per second!

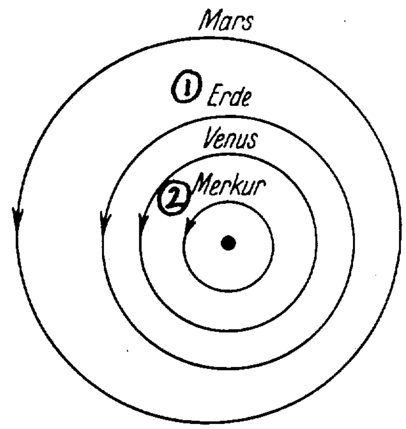


Figure 97. Enhanced view taken from Figure 96 of the orbits of Mars, the Earth, Venus and Mercury.

Key: 1. Earth; 2. Mercury.

And yet how tiny this world is compared to the /165
incomprehensible distances of the universe, from which those many molten celestial bodies familiar to us as fixed stars transmit their illuminating greetings of radiation. Even the one closest to us, the fixed star Alpha-Centauri, is 4.3 light years away; i.e., it is around 4,500 times as far as the diameter of the entire solar system! All of the others are still many more light years away from us, most of them hundreds and thousands of light years. And if there are fixed stars closer to us which have already been extinguished, then we are unaware of them in the eternal darkness of empty space.

From this discussion, it can now be seen that only those stars belonging to the solar system can be considered whatsoever for the trip to alien celestial bodies, according to the view held today.

## The Technology of Space Travel

Just exactly how the distance trip is supposed to take place through outer space has already been indicated at the beginning of this book[30]: in general, in free orbits around those celestial bodies in whose predominant gravitational field the trip is proceeding. Within its empire, the sun must consequently be continually orbited in any free orbit, thus preventing the space ship from coming under its gravitational force and crashing into its molten sea.

In this regard, we do not have to take any special /166
precautions as long as we stay close to the Earth or to another heavenly body of the solar system. After all, any body orbits the sun in its own free orbit, as do all bodies belonging to it at the same time. At the velocity of the Earth (30,000 meters per second), the moon, for example, also circles the sun, as does our future space station (both as satellites of the Earth). As a result, the sun's gravitational force loses its direct impact on those two satellites ("stable state of suspension" compared to the sun).

Only when the space ship further distances itself from the more confined gravitational region of a celestial body circling the sun, the sun would then have to be orbited in an independent free orbit. If, for example, the trip is supposed to go from the Earth to an alien planet, then, based on previous calculations, both the path of this independent orbit and the time of departure from the Earth must be selected in such a fashion that the space ship arrives in the orbit of the destination planet approximately at that point in time at which the encounter point is itself passed through by the planet.

If the vehicle is brought in this fashion into the practical effective range of gravity of the destination celestial body, then the possibility exists either to orbit the body in a free orbit as a satellite as frequently as necessary or to land on it. The latter can, if the

---

[30] See Pages 9 and 10.

celestial body has an atmosphere similar to that of the Earth's, occur in the same fashion as previously discussed[31] for the Earth (Hohmann's landing manoeuver, Figures 44 and 45). If, however, a corresponding atmosphere is absent, then the landing is possible only by reaction braking, that is, by operating the propulsion system counter to the direction of descent during landing[32] (Figure 37).

To travel then to another celestial body within the /167
solar system after a successful escape from the original body, the orbital motion, which was previously effected simultaneously with this body around the sun, must be altered by using the propulsion system to such an extent that the space ship would achieve an independent orbit around the sun as a result, which links its own orbit with that of the other star. To implement this in accordance with the laws of celestial mechanics, the original orbital movement would have to be accelerated if the vehicle (corresponding to the position of the destination) was supposed to distance itself in this case from the sun (Figure 98) and to be decelerated if it was supposed to approach it. Finally as soon as the destination heavenly body is reached, the independent motion maintained in the "transfer orbit" must be transitioned into that motion which must restrain the vehicle in relation to the new celestial body for effecting the orbiting or landing maneuver. The return trip would also have to take place in the same fashion. It can be seen that repeated changes of the state /168
of motion are necessary during the course of a long-distant trip of this nature through planetary space. The changes would have to occur through propulsion with an artificial force and, therefore, would require an expenditure of fuel,

---

[31] See Pages 80 to 87.

[32] See Pages 77 through 79.

a point previously mentioned in the beginning of this book[33]. As determined mathematically by Hohmann, the fuel expenditure becomes the least when the orbit of the original celestial body and that of the destination star are not intersected by the transfer orbit of the vehicle, but is tangential to it (touches it) (Figure 99). Nevertheless, the required amounts of fuel are not insignificant.

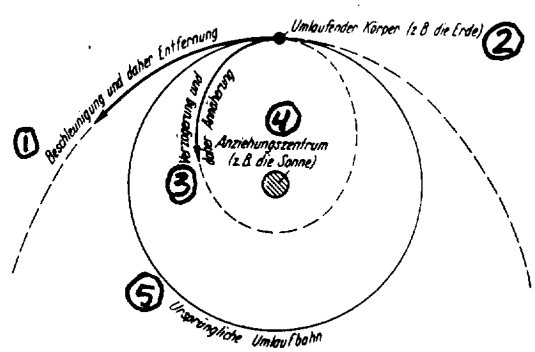


Figure 98. If the motion of a freely orbiting body is accelerated, then it expands its original orbit and distances itself from the center of gravity. If the motion is decelerated, then the body approaches the center of gravity by contracting its orbit.

Key: 1. Acceleration and, therefore, distancing; 2. Orbiting body (e.g., the Earth); 3. Decelerating and, therefore, approaching; 4. Center of gravity (e.g., the sun); 5. Original orbit.

Besides the points discussed above, there are additional considerations if the destination heavenly body was not to be orbited, but was supposed to be landed on. These considerations are all the more important the greater the mass and consequently the gravitational force of the destination star are, because the re-ascent from the destination star when starting the return trip requires, as /169

[33] See Page 10.

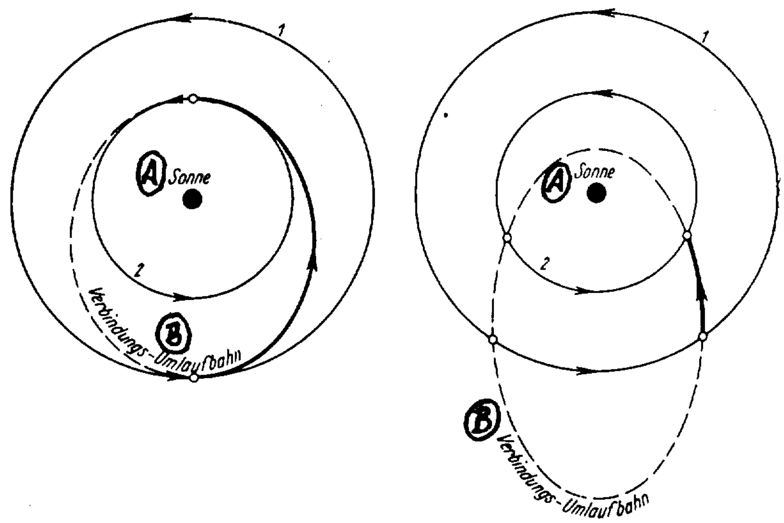


Figure 99. Tangent to intersecting a transfer orbit in which the space vehicle must move independently in order to reach an alien celestial body within the solar system. The numbers in the figure indicate the following: 1. the orbit of the original body; 2. the orbit of the destination celestial body. The distance of the transfer orbit marked as darkened lines is that part of the orbit which the vehicle actually travels through.

Key: A. Sun; B. Transfer orbit.

we already know from the discussion[34] of the Earth, a very significant expenditure of energy. Additionally, if braking must be performed during the landing by propulsion in the absence of an appropriate atmosphere (reaction braking), then a further, significant multiplication of the necessary fuels results from this.

The fuels must, however, be carried on board from the Earth during the outward journey, at least during the initial visit to an alien star, because in this case we could not expect from the outset to be able to obtain the necessary fuels from the star for the return trip.

---

[34] See Pages 49 through 52.

## Launching from the Earth's Surface

If a trip of this nature would now be launched directly from the Earth's surface, then this entire amount of fuel would have to be first separated from the Earth (by overcoming its gravitational force). According to what was stated previously[35], a extraordinary expenditure of energy is necessary for this purpose, however.

For the present case and at least for the efficiency of currently available fuels, the amount to be carried on board would accordingly constitute such a high percentage of the total weight of the vehicle that its construction would hardly be possible.

The only visit to a celestial body, which could probably be undertaken directly from the Earth's surface with fuels known to date, would be an orbiting of the moon for researching its surface characteristics in more detail, in particular, the side of the moon continually facing away /170 from the Earth. During this trip, the space ship could also be "captured" by the moon in order to circle it as frequently as necessary in a free orbit as a moon of the moon. The amount of fuel necessary for this effort would not be much greater than for an normal ascent from the Earth up to the practical limit of gravity.

## The Space Station as a Base for Travel into Distant Space

The conditions, however, would be considerably more favorable if a fuel depot appropriately suspended high over the Earth and continuously circling it in a free orbit was built, as Oberth suggests, and if the trip was started from this depot instead of from the Earth's surface. Because in that case only a minimal expenditure of energy would be

---

[35] See Pages 49 through 52.

necessary for a complete separation from the Earth and the vehicle need not, therefore, be loaded with the fuel necessary for the ascent from the Earth. It would have to carry on board only slightly more than that amount necessary for the long-distant trip itself.

Since the depot would be in a weightless state as a result of its free orbital motion, the fuels could simply be stored there freely suspended in any amount and at any place in the depot. Protected against the sun's rays, even oxygen and hydrogen would keep in a solid state for an arbitrarily long time.

Their resupply would have to be accomplished by a continuous space ship shuttle service as follows:

either from the Earth where the fuels (at least ones consisting of liquid oxygen and hydrogen) could be produced, by way of example, in large power plants powered by the heat of the tropical seas;

or from the moon, as Max Valier suggests. This method /171
would be particularly advantageous, because since the mass and consequently the gravitational force of the moon are considerably smaller than those of the Earth, the expenditure of energy necessary for the ascent and consequently for the fuel supply for that ascent would be significantly less. However, this assumes that the required raw materials would, in fact, be found on the moon, at least water (in a ice-like condition, for instance) would be available there, because water can be decomposed electrolytically into oxygen and hydrogen, the energy for this process being provided by a solar power plant. Unfortunately, the probability for this is not all that high.

If, however, it was possible, then even the moon, according to Hohmann's recommendation, could be used as a starting point for long-distance travel into outer space; that is, build the fuel depot on the moon.

Despite many related advantages, Oberth's recommendation of a freely suspended depot appears the better one, because the complete separation from the gravitational field of the Earthly realm (including the moon) would require considerably less expenditure of energy from a depot of this nature. More specifically, it would certainly be the most advantageous from an energy economics point of view to build the depot one or many millions of kilometers away from the Earth, especially when the fuels must be supplied from the Earth.

We want, however, to relocate the depot to our space station and as a result to make it a transportation base, because it is already equipped with all equipment necessary for this purpose in any case.

Of this equipment, giant telescopes, among others, would be particularly valuable because thanks to their almost unlimited efficiency they would not only make it possible to study in detail the destination regions of the stars from a distance, a point previously described[36]. The ground could probably keep the space ship under constant /172 surveillance during a large part of its trip, in many cases perhaps even during the entire trip, and could remain in at least one-sided communications with it through light signalling to be emitted at specific times by the space ship.

Thus, the space station, besides satisfying the many assignments already discussed, would be able to satisfy those which assist not only in preparing for actual travel into the universe, but which also serve as a basis for the entire long distance transportation into outer space.

## The Attainability of the Neighboring Stars

---

[36] See Page 177.

Hohmann has studied in detail the problem of traveling to alien celestial bodies. According to his results, the long-distance trip would last 146 days from the Earth to Venus and 235 days to Mars, expressed in a terrestrial time scale. A round trip including a bypass both of Venus and Mars in the relatively minimal distance of approximately 8 million kilometers could be carried out in about 1.5 years. Not quite 2.25 years would be necessary for a visit to Venus with a landing, including a stay there of 14.5 months and the traveling to and back.

Assume now the following: in the sense of our previous considerations, the trip would start from the space station, so that only a minimal amount of energy would be necessary for the complete separation from the Earth's gravitational field, and the return trip would take place immediately to the Earth's surface, so that no energy whatsoever would have to be expended, because in this case the possibility would exist to descend using only air drag braking. The load to be transported is as follows: 2 people including the supplies necessary for the entire trip and all instruments required for observation and other purposes.

It then follows from Hohmann's calculations that the /173 vehicle in a launch-ready condition, loaded with all fuel necessary for traveling to and back, would have to weigh approximately the following: 144 tons for the described round trip with a bypass of Venus and Mars, of which 88% would be allocated to the fuels, 12 tons for the first landing on the moon, 1350 tons to Venus and 624 tons to Mars. For the trip to the moon, 79% of the entire weight of the vehicle would consist only of the fuel carried on board, yet approximately 99 % for the trips to Venus and Mars. A 4,000 meter per second exhaust velocity was assumed in these cases.

It is clear that the construction of a vehicle which is supposed to carry amounts of fuel on board constituting 99%

of its weight would result in such significant engineering difficulties that its manufacture would initially be difficult to accomplish. For the present and when considering our larger neighboring stars, only the moon would, therefore, be a possibility for a visit with a landing, while the planets could in the best case be closely approached and orbited, without descending to them, however. Nevertheless it can be hoped that mankind will finally succeed in the course of time – more specifically by employing the staging principle explained in the beginning[37] – even with today's known engineering resources in building such space rockets which permit carrying out landings on our neighboring planets.

With the above and when considering the present state of science, all possibilities are probably exhausted which appear to present themselves in the best case for space ship travel. Then, the difficulties would be much greater confronting a visit to the most distant stars of the solar system. Not only are the distances to be travelled to those destinations longer by a multiple than the ones previously considered, but since all of these celestial bodies are at a completely different distance from the sun than the Earth, the sun's gravitational field also plays a significant role in their attainability. Because if, by way of example, we /174
distance ourselves from the sun (i.e, "ascend" from it) in the same fashion as would be necessary in the case of the Earth's gravitational field, then the sun's gravitational field must be overcome by expending energy, expressed as the change of the orbital velocity around the sun, which was previously discussed[38] and which is required in long-distance travels through planetary space.

---

[37] See Pages 52 through 55.

[38] See Pages 186 through 188.

If, however, we also wanted to descend down to one of these celestial bodies, then enormously large amounts of fuel would be necessary, in particular for Jupiter and Saturn because they have very strong gravitational fields as a result of their immense masses.

In accordance with the above discussion and solely because of their enormous distance, we naturally cannot even think of reaching the fixed stars at the present time.

## Distant Worlds

This doesn't mean to say that we must remain forever designated to the Earthly realm and to its nearest celestial bodies. Because if we could succeed in increasing further the velocity of repulsion exceeding that rate of approximately 4,000 (perhaps 4,500) meters per second when generating the thrust, the highest attainable in practice at the present time, and/or in finding a possibility for storing on board very large quantities of energy in a small space, then the conditions would be completely different.

And why shouldn't the chemists of the future discover a fuel which surpasses on effectiveness the previously known ones by a substantial degree? Yes, it would even be conceivable that with time mankind will succeed in making technical use of those enormous amounts of energy bound up in matter, whose presence we are familiar with today, and in using it for the propulsion of space vehicles. Perhaps mankind will someday discover a method to exploit the /175 electrical phenomenon of cathode radiation, or otherwise in some way attain a multiple increase of the velocity of repulsion through electrical influence. Even utilizing solar radiation or the decay of radium, among others, are also possibilities in satisfying this purpose.

In any case, natural possibilities for researchers and inventors of the future are still available in many ways in this regard. If success results from these efforts, then probably many other of those alien worlds seen by us only as immensely far away in the sky filled with stars would be visited by us and walked on.

An ancient dream of mankind! Would its fulfillment would be of any use to us? Certainly, extraordinary benefits would accrue to science. Regarding the practical value, any unambiguous judgement is not possible today, however. How little we know even about our closest neighbor under the stars!

The moon, a part of the Earthly realm, our "confined native land" in the universe, is the most familiar to us of all the alien celestial bodies. It has grown cold, has no atmosphere, is without any higher life form: a giant rock-filled body suspended in space, full of fissures, inhospitable, dead -- a bygone world.

However, we possess significantly less knowledge about the celestial body observed the best after the moon, about our neighboring planet Mars, even though we know relatively quite a bit about it in comparison to the other stars.

It is also an ancient world body, although considerably less so than the moon. Its mass and, consequently, its gravitational force are both considerably smaller than that of the Earth. It has an atmosphere, but of substantially lower density than the terrestrial one (the atmospheric pressure on its surface is certainly significantly lower than even on the highest mountain top on Earth). Even water is probably found on Mars. However, a fairly large part of it is probably frozen, because the average temperature on /176
Mars appears to be substantially below that of the Earth's, even though at certain points relatively significant degrees of heat were detected, such as in the Martian equatorial region. The temperature differences between night and day are considerable due to the thinness of the atmosphere.

The unique and most frequently discussed of all Martian observations is the appearance of the so-called "Martian canals." Even thought in recent times they are considered in many cases as only optical illusions, it is still unclear just exactly what they are.

In any case, the present knowledge about Mars does not provide sufficient evidence to be able to form a final judgement as to whether this celestial body is populated by any form of life or even by an intelligent one. For mankind on Earth, Mars would hardly be livable, primarily because of the thinness of its atmosphere. From a scientific point of view, it would certainly offer space ship travel an immensely interesting research objective. Whether walking on Mars would have a practical value can still not be acknowledged with certainty today; however, it appears to be less probable.

It is an altogether different situation with the second planet directly adjacent to us, Venus, the brightly shining star familiar to us as a "morning and evening star." Its size as well as its mass and accordingly the gravitational effect existing on its surface is only slightly smaller than that of the Earth's. It also has an atmosphere which should be quite similar to the terrestrial one, even though somewhat higher and denser than the Earth's. Unfortunately, Venus can be observed only with difficulty from the Earth's surface, because it always appears in a perihelion and, therefore, becomes visible only at dawn. As a result, its rotation is still pretty much unclear to us. If Venus rotates in approximately 24 hours roughly like the Earth, a point assumed by many parties, then an extremely comprehensive similarity would exist between Venus and Earth.

In the case of this planet, finding conditions of life /177
similar to terrestrial ones can be anticipated to a high degree, even when the assumption should in fact be valid

that it is continually surrounded by a cloud cover. Because even on Earth, highly developed forms of plant and animal life already existed at a time when apparently a portion of the water now filling the seas and oceans was still vapor-like due to the limited advance of the cooling off of the globe millions of years ago and, therefore, continually surrounded our native planet as a dense cloud cover. In any case, Venus has the most probability of all the celestial bodies known to us of being suitable for colonization and, therefore, of being a possible migration land of the future. Furthermore, since it is located the closest to us of all planets, it could be the most captivating destination for space ship travel.

Mercury offers even more unfavorable conditions for observation than Venus because it is still closer to the sun. Of all the planets it is the smallest, has an atmosphere which is no doubt extremely thin and surface conditions which apparently are similar to those of the moon. For this reason and especially due to its large perihelion (solar radiation around 9 times stronger than on the Earth!), extremely unfavorable temperature conditions must exit on it. Consequently, Mercury should be considerably less inviting as a destination.

Nevertheless, if it was still possible when evaluating the stars discussed above to arrive at a fairly reasonable result, then the current knowledge about the most distant planets, Jupiter, Saturn, Uranus and Neptune, is hardly sufficient to this end. Of course, we have been able to determine that all of them have dense atmospheres. The question of surface conditions of these celestial bodies is, however, still entirely unclear: in the cases of Jupiter and Saturn, because they are surrounded by products of condensation (clouds of all types) which are so dense that we apparently cannot even see their actual surface; and in the case of Uranus and Neptune, because their great distance precludes precise observation.

Therefore, anything regarding their value as a space flight destination can only be stated with difficulty. Yet, the following condition by itself is enough to dampen considerably our expectations in this regard: a relatively very low average density has been determined for these planets (1/4 to 1/5 of that of the Earth's), a condition indicating physical characteristics quite different from those on Earth. /178

It would be perhaps more likely that several of the moons of these celestial bodies (primarily, those of Jupiter would be considered to this end) offer relatively more favorable conditions.

One thing is for sure in any case: that the mass greater by a factor compared to that of the Earth's and that the powerful gravitational fields of these planets caused as a result would make a visit to them extraordinarily difficult, especially in the cases of Jupiter and Saturn.

Regarding the remaining, varying types of world bodies which still belong to the solar system, it can be said with a fair degree of certainty today that mankind would hardly be able to benefit in a practical sense from a trip to them.

We see then that, generally speaking, mankind may not indulge in such great hopes regarding the advantages which could be expected from other celestial bodies of our solar system. In any case, we know much too little about them in order not to give free reign to the flight of thoughts in this regard:

Of course, it could be that all of these worlds would be completely worthless for us! Perhaps, we would find on some of them a fertile soil, plant and animal life, probably of a totally alien and unique nature for us, or probably of a gigantic size, as previously existed on Earth. Yes, it would not be inconceivable that we would meet even people or similar types of life, perhaps even with civilizations very different or even older than those of our native planet.

It is highly probable that life on the alien stars – if /179 it exists there at all – is at another stage than that on Earth. We would be able then to experience that wonderful feeling of beholding images from the development of our terrestrial being: current, actual, living and yet – images from an inconceivable, million-year old past and/or equally distant future.

Or that we would discover especially valuable, very rare Earthly materials, radium for example, in large, easily minable deposits?

And if the living conditions found there are also compatible for a long stay by us, then perhaps even alien celestial bodies will one day be possible as migration lands – regardless of how unbelievable this may sound today.

That such stars exist in those of our solar system is, nevertheless, only slightly probable according to what has been stated previously, with the exception of Venus, as already noted.

### Will It Ever be Possible to Reach Fixed Stars?

It would be much more favorable, however, when the stars outside of our solar system could be considered in this context, because the number is enormous only of those celestial bodies which, since they are in a molten state, are visible to us and, therefore, are familiar as fixed stars. Many of these are similar to our sun and, as powerful centers of gravity, are probably orbited exactly like the sun by a number of small and large bodies of varying types.

Shouldn't we expect to find among these bodies ones similar to our planets? Of course, it would be too far into the future to perceive them; however, probability speaks strongly for their existence. Yet, the most recent scientific research – as one of its most wonderful results – has been able to show that the entire universe, /180 even in its most distant parts, is both controlled by the same natural laws and structured from the same material as the Earth and our solar system! At other locations within the universe, wouldn't something similar, in many cases almost the same thing, have to materialize under the same conditions (from the same matter and under the effect of the same laws) as in our case?

It is certainly not unjustified to assume that there would be other solar systems more or less similar to ours in the universe. And included in their numerous planets, there surely would be some which are almost similar to the Earth in their physical and other conditions and, therefore, can be inhabited or populated by people from Earth, or presumably they may already be populated in the first place by some form of life, even an intelligent one. At least the probability is significantly greater that this, in fact, is the case than if we only consider in this regard the relatively few stars of our solar system.

Yet, would it be conceivable at all that those immeasurable distances still separating us, even from the closest of these fixed stars, could be traveled by mankind, taking only into account the restriction, which is established when prolonging a trip over time through the average life span of a person, completely ignoring the related necessary technical performance of the vehicle?

Assume initially that that goal which appears astonishing even for today's concepts has been achieved: refining the reaction propulsion system to such an extent that an acceleration of approximately 15 $m/sec^2$ could be continually imparted to the space ship over a very long time, even through years. Humans would probably tolerate this acceleration over long periods through a gradual

acclimatization. To travel a given distance in space, it would then be possible to accelerate the vehicle continually and uniformly over the entire first half of its trip, this is, to give it more and more velocity, and to decelerate it /181
in the same way over the second half and consequently to brake it gradually again (Figure 100). Depending on the method, a given distance is sped through in the shortest possible achievable time at a predefined, highly reliable acceleration and/or deceleration.

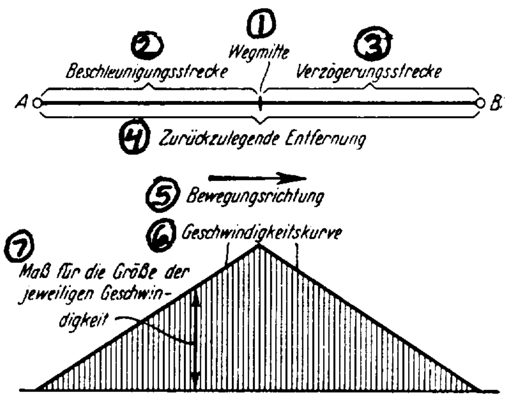


Figure 100. Covering a distance when the vehicle is uniformly accelerated over the entire first half of the distance and similarly the vehicle is decelerated over the second half. The highest velocity of motion resulting from this method is at the mid-point.

Key: 1. Mid-point; 2. Accelerated over this distance; 3. Decelerated over this distance; 4. Distance traveled; 5. Direction of motion; 6. Velocity curve; 7. Scale for the rate of the prevailing velocity.

If the trip now took place to neighboring fixed stars in this manner, then the following time periods would result for the entire round trip (as would have to be the case in the initial round trip visit) based on mathematical calculations: 7 years to Alpha-Centauri, the star known to be the closest to us, and 10 years to the four fixed stars next in distance; numerous fixed stars could be reached in a total travel time of 12 years.

However, it is quietly assumed here that the development of every velocity, even the large ones, is possible in empty ether space. In accordance with the theory of relativity, a velocity greater than the speed of light of 300,000 km per second can never be attained whatsoever in nature.

If this is taken into account and if it is assumed at the same time that otherwise no obstacle (one currently unknown to us, perhaps inherent in the nature of universal world ether) would prevent us from attaining travel velocities approaching the magnitude of the speed of light, then we could, nevertheless, reach the fixed star Alpha-Centauri in around 10 years, the four further ones in 20 years and a considerable number of neighboring fixed stars presently known to us in 30 years; the durations represent total round trip travel times.

For the one-way trip, as would be the case for /182
continual traffic, half of the times would suffice.

No doubt, trips of such duration would be fairly close to the limit of human endurance; however, they cannot yet be designated as completely non-implementable, since no fundamental obstacle can, in fact, be seen in this regard for reaching the closest fixed stars.

Meanwhile, the question still remains open as to whether vehicles could ever be built having the technical perfection necessary for such performances? However, even this question cannot be answered with an unequivocal no because, as has been pointed out previously[39], natural phenomena exist instead, such as exploiting the energy bond up in matter by smashing atoms or utilizing the decay of radium, of cathode radiation, etc.

Admittedly, we are far away today from that goal of completely mastering such natural phenomena to such an

---

[39] See Pages 193 and 194.

extent that mankind would be able to use them in an engineering sense for present space travel purposes! And whether this will be successful at all?

As far as is humanly possible to tell, the sons of our time will hardly achieve this. Therefore, the fixed stars, which conceal very important secrets of the universe in their immensity, will no doubt remain unreachable for them. Who can say what scientific triumphs and technical potentials distant times will bring! Since mankind has now become confident with scientific reasoning, what tremendous progress is signified today by only a few decades; and what are a hundred, even a thousand years in that space of time of human development still ahead of us.

Conquering space! It would be the most grandiose of /183 all achievements ever dreamed of, a fulfillment of the highest purpose: intellectual accomplishments to save mankind before its final plunge into eternity. Because for our entire being to acquire a real meaning and for mankind to be justified in feeling set by God as an agent of a higher cause – yet one created by mankind himself –, and, if all of what mankind with its acts and hopes and with that which he has achieved over many thousands of years of striving is to be nothing more than just a whim of a cosmic adventure, a random event in eternal nature's game which comes into being and dies away with the small globe of the Earth, so large only for us and yet so tiny in the universe, we must succeed in transplanting our civilization and thus in spreading it over the entire universe.

## The Expected Course of Development of Space Travel

Now let us turn back from these dreams of the future to the reality of the present. That would really be an event today if we could succeed in lifting an unmanned rocket several 10s or even 100s of kilometers! Even though the problems associated with space travel have been worked out theoretically to some degree thanks to the many sided efforts of the last few years, almost everything still has to be accomplished from a practical standpoint. Therefore at the conclusion of this book, possible directions of space travel development are briefly outlined.

The first and most important point in this regard is, without a doubt, the engineering improvement of the rocket motor, the propulsion equipment of the space ship. This is a task which can be solved only in thorough, unselfish research. It is a problem which belongs first and foremost in the experimental laboratories of universities and on the test fields of reliable machine factories.

In connection with the above, experiences must be /184
accumulated (at least as far they address space rockets for a liquid fuel) in the related required method of applying liquefied gases, in particular liquid oxygen, then liquid hydrogen, among others. Furthermore, the behavior of metals at extremely low temperatures could be tested in laboratory experiments in order to determine the substance best suited as a construction material for space ships. Finally, the method of construction for the fuel tanks will also require detailed studies.

After solving these fundamental, engineering issues, the following could then be considered next: to let unmanned space rockets ascend into the higher layers of the atmosphere or even above them into empty outer space and to let them descend using a parachute, as far as the latter turns out to be achievable.

These experiments will make it possible not only to accumulate the necessary technical experiences vis-a-vis the functioning of the rocket mechanism, but in particular to also become familiar with the laws of air drag in effect at abnormally high velocities and of the laws of heating due to atmospheric friction, data which is of the utmost importance for shaping the vehicle itself as well as the parachutes, wings, etc. We will furthermore be able to determine up to what altitudes simple parachute landings are still reliable (taking into consideration the danger of combustion of the parachute due to atmospheric friction). As a result of these determinations, exact information can finally be obtained about the condition of the higher layers of the Earth's atmosphere, knowledge which forms one of the most important preliminary conditions for the further development of space travel, but would also be of great value in many other regards (radio engineering, for example).

Firing an unmanned space rocket loaded with flash powder at the moon, as recommended by many parties, could probably also be attempted as a subsequent step; it would have very little practical value, however.

In parallel with these efforts, we – in order to /185
prepare for the ascent of humans – would have to research the physical tolerance of elevated gravitational effects by performing appropriate experiments using large centrifuges (or carousels) and, furthermore, to create the possibility for remaining in airless space by fully refining the previous methods of supplying air artificially and by testing in a meaningful manner space suits in containers made airless and cooled to the lowest temperature.

As soon as the results of the previously delineated, preparatory work allow, ascents using an simple parachute landing can then be carried out (possibly following previous attempts with test animals) by means of manned space rockets up to altitudes determined beforehand as reliable for such flights.

Now we can proceed to equip the vehicles with wings to make them suitable for the glided flight landing (Hohmann's landing manoeuver) and consequently for attaining those altitudes from which a simple parachute landing would no longer be feasible.

Experience in the engineering of the reaction propulsion system necessary for building such airplane-like space ships (or expressed in another way: airplanes powered by reaction, that is "reaction airplanes," "rocket airplanes," etc.) and experience with atmospheric friction, air drag, etc. will both have been gained at this time from the previously described preliminary experiments made with unmanned space rockets.

When testing these vehicles, which would have been performed by evaluating as extensively as possible previous experiences with aviation, we will first start with relatively short flight distances and altitudes and strive to increase these distances and altitudes, gradually at first, then more and more through a corresponding increase of the highest velocities.

As soon as maneuvering with rocket airplanes in general /186 and especially the flight technology necessary at cosmic velocities in the higher, thin layers of air are mastered, the following occur at the same time and of their own accord:

1. Creating terrestrial "express flight transportation at cosmic velocities," as explained in the beginning of the book; that is, the first practical success of space flight is attained (every ascent of this type not flown above the atmosphere with a glided flight landing is strictly speaking nothing other than an express flight of this nature);

2. Making possible the fact that returning space ships can now descend using a glided flight landing (instead of a simple parachute landing); i.e., the safe return to Earth from any arbitrary altitude is assured as a result, an accomplishment which is of the greatest importance for space flight and which signifies an essential precondition for its implementation.

This previously described development course (first performing ascents using unmanned space rockets with a simple parachute landing and, only on the basis of the experiences amassed during these ascents, stepping up to developing the reaction airplane) should presumably be more practical than developing this airplane directly from today's airplane, as has been advocated by another party, because experiences to be accumulated initially during this development will probably force a required method of construction for the rocket airplane which may differ considerably from those methods for airplanes known to date. To arrive, however, at this probable result solely via experiments with airplanes (which are costly), should presumably be significantly more expensive and moreover entail much more danger.

In any case, the most important effort is that practical experiments are started in the first place.

By a gradual increase in the performance of reaction airplanes or airplane-like space ships, more significant horizontal velocities and altitudes will finally be attained over time, until finally free orbital motion above the atmosphere and around the Earth will result on its own accord. Arbitrarily selecting the orbit will no longer present any difficulties.

Then the potential for creating the previously /187
described space station, that is, achieving the second practical success in the development of space travel, is already given.

Also, random high ascents could now be undertaken and the moon orbited as the occasion permits.

Both express flight transportation and the space station are purely terrestrial matters. Now we will strive to realize the additional goals of space flight while using the space station as a transportation control point: walking on the moon, if possible building a plant on the moon for producing fuels, orbiting neighboring planets, and other activities which may otherwise prove doable.

## Final Remarks

Even if contrary to expectations we were not successful today in attaining in a truly practical manner the higher exhaust velocities necessary for the goals mentioned above using sufficiently simple systems and even if the velocity could be raised only up to approximately 2,000 - 3,000 meters per second, then space flight would nevertheless lead in the short term at least to being able to research thoroughly the Earth's atmosphere up into its highest layers and especially – as a direct practical benefit – to create the described terrestrial express flight transportation at cosmic velocities, until subsequent times finally bring the realization of the other goals.

By just accomplishing the above goals, success would be achieved which would far overshadow everything previously created in the technical disciplines. And in any case it can no longer be doubted that this would at least be achievable even today with a determined improvement of available engineering possibilities. This will be /188
successful that much sooner the earlier and in the more large-scale and more serious scientific manner, mankind faces the practical treatment of the problem and if he does not surrender to any disappointment about the extent of the difficulties to be overcome.

Nevertheless, the purpose of the present considerations is not one of wanting to convince anyone that mankind will be able tomorrow to travel to alien celestial bodies. I have only attempted to show that traveling into outer space should no longer be viewed as something impossible for mankind, but presents a problem which can be solved very reliably in a technical manner. On account of the overwhelming greatness of the deeds being strived for during this effort, it is a problem which must let all obstructions still standing in the way of its final mastering appear only insignificant.

Please pay attention to the following pages. /189

**N A S A**
National Aeronautics and Space Administration

# Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| TT - 10002 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| The Problem of Traveling in Outer Space<br>The Rocket Motor | JUNE 1993 |
| | 6. Performing Organization Code |
| 7. Author(s)<br>Hermann Noordung | 8. Performing Organization Report No. |
| | 10. Work Unit No. |
| 9. Performing Organization Name and Address<br>NATIONAL AERONAUTICS AND SPACE ADMINISTRATION<br>WASHINGTON D.C. 20546 | 11. Contract or Grant No<br>NASW - 4693 |
| | 13. Type of Report and Period Covered<br>TRANSLATION |
| 12. Sponsoring Agency Name and Address<br>NATIONAL AERONAUTICS AND SPACE ADMINISTRATION<br>WASHINGTON D.C. 20546 | 14. Sponsoring Agency Code |

15. Supplementary Notes
Translation from German to English of "Das Problem der Befahrung des Weltraums, Der Raketen-Motor," Richard Carl Schmidt & Co.: Berlin, 1929, 188 pp.

Translated by SCITRAN P.O.BOX 5456 SANTA BARBARA CA 93150.
TEL. 805/969-2413 FAX 805/969-3439. CIS 71046,1337

16. Abstract
This book is one of the first basic primers on space travel history. It covers the solar system and its related forces. It then discusses in some detail the problems associated with rockets and satellites. Several references are made to H. Oberth, considered by some to be the father of space travel.

| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
|---|---|
| | Unclassified<br>Unlimited |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of pages | 22. Price |
|---|---|---|---|
| unclassified | unclassified | 209 | |

NASA FORM 1626 OCT.86